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AN EXPLORATORY INVESTIGATION INTO THE ERROR DETECTION CAPABILITIES OF LOW AND HIGH HANDICAPPED GOLFERS

by

SHANNON S. D. BREDIN ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment

of the requirements for the degree of Master of Science

Faculty of Physical Education and Recreation

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled An Exploratory Investigation into the Error Detection Capabilities of Low and High Handicapped Golfers submitted by Shannon S. D. Bredin in partial fulfillment of the requirements for the degree of Master of Science.

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ABSTRACT

Although it is generally accepted that skilled performers possess a greater capability for detecting errors than novice performers (Fitts & Posner, 1967), empirical evidence supporting this notion has been derived utilizing simple tasks, novel to the performer (e.g., ballistic timing tasks). The present studies were designed to investigate the error detection capabilities of skilled and novice performers on a complex motor skill. More specifically, this project examined the accuracy with which low (LOW) and high (HIGH) handicapped golfers ($\leq$10 vs 20-30, respectively) estimated their motor performance regarding clubface angle (CA), impact point (IP), and swing path (SP) when vision of flight trajectory was occluded. Motor performance measurements were obtained using a GolfTek Pro V Swing Analyser™, which was found to provide valid and reliable measurements in Study 1. Study 2 revealed superior judgements of movement production accuracy by LOW participants, in comparison to HIGH, for IP. With the inclusion of a pre-test calibration set, Study 3 revealed superior judgement accuracy by LOW, in contrast to HIGH, on all clubface variables (CA, IP, and SP). Results of Study 2 and 3 indicate that skilled performers judge their motor performance with greater accuracy than novice performers, which suggests that skilled performers possess a more developed mechanism to detect and perceive motor performance discrepancies. Furthermore, the capability to detect and accurately label movement error may be relatively specific to the feedback condition under which practice occurs.

DEDICATION

This project is dedicated to my mom and dad for always providing me with unlimited opportunities and who always put up with every inconvenience in the pursuit of my goals.

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ABBREVIATIONS

A list of abbreviations used in this thesis is presented below.

ABBREVIATION	DEFINITION
AE	Absolute error
CA	Clubface angle
E	Total variability
HIGH	High handicapped group
IP	Impact point
KR	Knowledge of results
LOW	Low handicapped group
SP	Clubhead swing path

LIST OF OPERATIONAL DEFINITIONS

Operational definitions for words commonly used in this thesis are provided alphabetically in the following list.

***Absolute error (AE)*:** The absolute unsigned deviation between a participant's estimate of performance and his actual motor performance score (criterion), which represents a measure of overall error.

Augmented information/feedback: Refers to feedback regarding the performance of a motor skill that enhances sensory information, which comes from a source external to the performer (Buekers & Magill, 1995; Magill, 1993).

Closed-loop control system: A system of motor control which, operates on the basis of feedback from different sensory-perceptual systems of the body. Feedback is compared to a standard or reference of correctness for the computation of error so that subsequent corrections can be executed to attain a desired state (Magill, 1993; Schmidt, 1988).

Closed motor skill: A physical action performed in a stable or predictable environment where the performer determines when the action begins (Magill, 1993; Schmidt, 1988).

Complex motor skill: A physical action involving both gross and fine musculature for the successful execution of and smooth co-ordination of significant number of parts or components to achieve a particular task goal.

Discrete motor skill: A physical action that has a distinct beginning and end point. The performer must adhere to both the beginning and end point boundaries if the task is to be performed successfully (Magill, 1993).

Error: Refers to an inappropriate action committed while performing a motor task (Ohlsson, 1996) and may arise as a consequence of incorrectly evaluating the environmental display (Rose, 1997).

Error signal: Features or patterns of features that indicate incorrect actions (Ohlsson, 1996) to the performer.

Expertise: Those individuals who possess a consistent record of excellence in a particular domain where the outstanding behaviour is attributed to relatively stable characteristics (Ericsson & Smith, 1991).

External feedback: External (exteroceptive) information received during and/or after the response from the environment or some additional source (Shea, Shebilske, & Worchel, 1993).

Exteroception: The perception of an environment based on information transmitted from such sensory receptors as vision and audition (Shea et al., 1993).

Golf swing: A discrete motor skill that takes place in a relatively closed environment and requires the smooth execution of the large musculature to successfully achieve the goal of the task, a complex motor skill.

Gross motor skill: A physical action characterised as involving large musculature where the successful execution and smooth co-ordination of the movement is essential for skilled performance (Magill, 1993).

Intrinsic feedback: Internal (proprioceptive) feedback normally received during and after the execution of a task (Shea et al., 1993).

Knowledge of results (KR): Verbalized (or verbalizable) post-response information regarding the outcome of a response in the environment (Schmidt, 1988). Associated with the augmented or external sources of information that can be used by the performer in the next task trial (Singer, 1975).

Motor skill: Refers to the voluntary physical movement of the body and/or limb in a highly specific response sequence to accomplish the goal of an action or task (Magill, 1993; Singer, 1980).

Perception: The active process of organizing, interpreting, and labelling incoming sensory information to provide meaning (Kerr, 1982; Magill, 1993).

Performance variability: Mean standard deviation of actual motor performance.

Proprioception: The perception of body part status based on sensory receptors (e.g., proprioceptors such as muscle spindles) that provide information about the current state of the body (Shea et al., 1993).

Response-produced feedback: Sensory information that is contingent on having produced a movement (Schmidt, 1988). Typically associated with self-regulated stimulation through movement and closed-loop control models whereby information is available to the performer as a result of his or her own efforts, an internalized process (Singer, 1975).

Self-regulation: An individual's capacity to control, govern, or direct his/her own actions through self-imposed rules of regulations that better adapt his/her performance to different circumstances and surroundings (Ferrari, Pinard, Reid, & Bouffard-Bouchard, 1991). In a broad sense, any effort by a human being to alter his/her own responses (Baumeister, Heatherton, & Tice, 1994).

Skill[1]: A term used to communicate a quality of performance or degree of proficiency which is often subjectively established by characteristics of the performance (e.g., consistency) or how well the goal of the task was accomplished (e.g., outcome, degree of productivity) (Magill, 1993).

Subjective reinforcement: A term used in Adams' Closed-loop theory (1971) and Schmidt's schema theory (1975). According to Adams (1971), subjective reinforcement refers to the capability of a learner to discern a difference between the feedback received and the perceptual trace; whereas, Schmidt (1975) uses the term to denote the labeled error signal that results when a raw sensory signal is converted into a reportable form.

Test-wiseness: A term used in educational psychology to denote a subject's capacity to utilize the characteristics and formats of the test or test-taking situation to receive a high score (Millman, Bishop, & Ebel, 1965).

Total variability (E)**:** The standard deviation of a set of performance estimation responses about a criterion (motor performance) which represents a measure of overall accuracy.

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[1] In general, the word 'skill' may take on different meanings depending on the context of its usage. For example, in one context, one might say "that man is a skilled golfer". However, in a different context, the sentence, "Chipping is an essential skill to golf", may be the appropriate word connotation (Magill, 1993). To eliminate any misunderstanding in this thesis, the term 'skill' will be used to indicate one's quality of performance; whereas, the term 'motor skill' will be used to denote a physical action or task.

LIST OF GOLF TERMINOLOGY

A list of golf terms commonly used in this thesis is presented in alphabetical order below. It is important to note that terms relating to clubface angle, swing path, and impact point, are defined here, and used throughout the text in reference to a right-handed player, unless otherwise stated.

Club: The implement or tool used to strike the golf ball.

Clubface: Refers to the part of the clubhead that strikes the ball (striking surface), but often is used to connote the entire clubhead when referring to clubface travel or other movement.

Clubface angle: A term used to denote the angle between the direction in which the clubface is facing and the target line. Proper clubface angle is "square" or 90 degrees to the target line; however, a clubface may also be angled to the right (open clubface) or left (closed clubface) as it meets the ball. It is one of three clubface parameters.

Clubface aspects/parameters: Denotes behaviour of the clubface at the moment of impact. There are three clubface aspects or variations (clubface angle, clubhead swing path, and impact point) which, interact to directly cause all the variations of ball travel direction and distance.

Clubhead swing path (SP): A term used to denote the horizontal direction of movement or path the clubhead takes on route to ball contact. The clubhead may travel directly along the target line or the clubhead path may travel toward the right of the target (inside-out path) or left of the target (outside-in path). It is one of the three clubface aspects.

Driver: Refers to the longest-hitting wood club, most often used on the tee in an attempt to achieve the greatest distance.

Handicap: A system designed to let golfers of all levels compete together on an equitable basis. It is an allowance in strokes given to an individual based on a player's gross score for a certain number of golf rounds (past and present) and the rating of the course where the rounds were played.

Heel: The aftward part of the clubface.

Hosel: The hollow portion of the clubhead where the shaft is attached, also referred to as the neck of the club.

Hook: A ball which travels in a curving line to the left of the target as a result of closing the clubface at impact and an exaggerated inside-out swing path.

Impact point (IP): A term used to denote the horizontal position on the clubface that meets the golf ball at contact. The optimal point with which to contact the ball is on the centre or "sweetspot" of the club; however, an off-centre may occur both forward, toward the toe of the clubface, or aft, toward the heel of the clubface. It is one of three clubface aspects.

Iron: A club with a metal head.

Par: The standard score in strokes assigned to each hole on the golf course.

Scratch Golfer: A player who possesses a zero handicap (0) and plays "par" golf.

Shank: To hit the ball with the heel of the clubhead where it joins the shaft (neck or hosel of the club); the ball travels directly to the right.

Shaft: That portion of the golf club between the grip and the clubhead.

Slice: A shot which starts left of the target before curving violently to the right with a rapid spinning motion as a result of opening the clubface at impact and swinging in an outside-in path; the most common ball flight for a beginner.

Sweetspot: The point on the clubface where clubhead weight is distributed such that, when the ball is hit by that point, the clubface will not tend to deviate from the angle it is facing. It is also referred to as the centre of the clubface.

Target: Refers to the flagstick on the green or position on the fairway at which the shot is aimed, the desired end of ball travel.

Target line: The straight, imaginary line extending from the ball to the target.

Tee: A structure upon which the ball is placed prior to teeing off with a driver or a three wood.

Three wood: Used primarily for distance shots when the ball is resting on the fairway; however, it is often used by women and younger golfers on the tee because it is shorter, lighter, and easier to control than the driver.

Toe: The forward part of the clubface.

CHAPTER ONE

INTRODUCTION

In recent years, there has been a growing interest in the study of motor expertise in a wide variety of motor tasks (e.g., baseball, basketball, figure skating, tennis, wrestling). As a consequence, an extensive descriptive database on motor expertise has accumulated, which outlines a variety of differences in perceptual capabilities between skilled and less skilled performers. Using approaches derived from cognitive psychology, evidence suggests that when motor experts are compared to novices within their own domain, they are reported to:

(a) be faster and more accurate at recognizing patterns;
(b) have superior knowledge of both factual and procedural matters;
(c) possess knowledge organized in a deeper, more structured form;
(d) have superior knowledge of situational probabilities;
(e) be better able to plan their own actions in advance;
(f) be superior in anticipating the actions of an opponent;
(g) be superior perceivers of essential kinematic information;
(h) perform in a less effortful, more automated fashion;
(i) produce movement patterns with greater accuracy;
(j) produce movement patterns of greater consistency and adaptability; and
(k) possess superior self-monitoring skills

(Abernethy, Thomas, & Thomas, 1993, p. 187).

In addition, classic theories pertaining to stages of motor skill acquisition (Fitts & Posner, 1967; Gentile, 1972), suggest that a common characteristic of people in the final stages of learning is the capability to identify their own errors and make adjustments to correct them (Magill, 1993). As such, it is generally accepted that experienced or expert performers possess a greater capability for detecting and correcting errors than novice performers (Buekers & Magill, 1995). As Ohlsson (1996) states, "it is natural to see skill acquisition as the successive elimination of errors" (p. 241). At this time, however, evidence supporting the notion that error detection capabilities improve as an individual's skill level improves, has been derived utilising simple, slow-graded or rapidly-executed, linear-positioning tasks, novel to the performer (Newell, 1974; Newell & Chew, 1974; Schmidt & White, 1972; Schmidt & Wrisberg, 1973, Expt 1). Consequently, the capability to detect error as it relates to motor expertise and the performance of highly complex motor skills (e.g., the breaststroke in swimming, the delivery of a curling rock, or shedding in Highland dance), lacks empirical evidence. Given the underlying importance of error detection capabilities to the overall regulation of motor performance, examining error detection from a complex motor skill perspective would serve to compliment existing literature in the study of motor behaviour and expertise.

Furthermore, establishing a link between the extensive descriptive database on motor expertise and the motor learning and control field is fundamental if the "desired progression from description of motor experts to the explanation of motor expertise" (Abernethy et al., 1993, p. 330) is to be made. In essence, such theoretical frameworks as Adams' (1971) closed loop theory and Schmidt's (1975) schema theory, may be extrapolated from the field of motor learning and control to the study of expertise. Whether it is the notion of a perceptual trace or a recognition schema, both theories imply a transition from reliance on externally-provided feedback to the development of an internally-derived mechanism that can maintain and even improve performance in the absence of augmented feedback (self-regulation). Therefore, it seems reasonable that a characteristic of expert performance might be the capacity to detect error. Investigating expertise differences in sensory monitoring and error detection is a potentially useful avenue to take for the eventual formulation of a model of motor expertise.

This study offers a unique contribution to the existing body of knowledge as it examines whether performers in the final stages of motor skill acquisition actually display greater error detection capabilities as compared to novice performers when executing a complex motor skill. In addition, this study focuses on error detection as it relates to motor expertise from contemporary motor learning and control perspectives.

Development of the Research Question: A Broader Perspective

Before presenting the research question of this project, it is important to acknowledge from where the idea was originally derived. The purpose of the following section is to provide the background to this project's development, as well as outline the significance of studying error detection from a much broader perspective.

Self-regulatory Behaviour and Error Detection

In the past, paradigms in motor learning have typically examined the learner under constrained conditions which have assigned "the executive function to the experimenter, rather than to the subject" (Butterfield & Belmont, 1977, p. 282). This means that the experimenter was in control of such variables as the number and rate of observation and practice trials, the learning strategies used, or the feedback schedule employed. Yet, we know that individuals learn at different rates, and exhibit a variety of learning styles and solutions to achieve a particular movement goal (Rose, 1997). Considering that an often recognized goal of education is to produce self-regulated learners (Zimmerman, 1994), it is essential to examine what occurs in the absence of scaffolding when learners are left to their own devices to monitor, evaluate, and implement change in their behaviours. In fact, differences in self-regulation may be a determining factor in the rate at which an individual develops competency in a motor skill (Ferrari et al., 1991). A shift towards a self-directed research approach whereby the learner has primary responsibilities in planning, implementing, and evaluating the effort, will provide us with an insight into how the learning process unfolds, from the individual's vantage point. As noted by Singer (1988), "knowing how to learn, how to monitor, how to evaluate progress, and how to implement suitable adaptive behaviours would appear to be learned capabilities that can underlie the early achievement in many activities, if not all of them" (p. 65).

Recently, Bouffard and colleagues have used the self-regulated approach to study independent, self-directed motor learning in children. When examining 10 and 12 year old children learning to replicate a novel, dance-like movement sequence, it was found that many of the participants were poor at recalling, detecting, and recognizing their own errors. Even more alarming, a failure to detect errors occurred when they watched a video-tape of themselves with a model they were trying to copy (Bouffard, Romanow, & Bredin, 1998). Such inadequacies in error detection have also been reported in other studies using dance sequences. For example, Laugier and Cadopi (1996) asked adult participants novice to dance, to identify differences between a model-sequence performed by an expert dancer and modified versions of the model sequence. Findings revealed that participants exhibited difficulty recognizing position differences when variation appeared in the middle of a sequence (e.g., the distance between the feet increased by 20 cm). In a study by Cadopi, Chatillon, and Baldy (1992, cited in Laugier & Cadopi, 1996), it was also reported that young participants displayed difficulty detecting position discrepancies, even when they occurred at the beginning of the dance sequence. Such findings have significant implication as the ability to detect errors is central to self-regulation. As noted by Zimmerman (1994), "it appears that the accuracy of one's self-monitoring directly influences one's capabilities to self-regulate performance outcomes" (p. 12). However, findings which display inadequacies in the detection of error should not come as a surprise. In most learning environments the focus is placed on performance and a lack of concern for the development of error detection capabilities in the learner is evident (Schmidt, 1988). Furthermore, error detection deficiencies have also been documented from the pedagogical side of the movement skill literature (Nielsen & Beauchamp, 1991). For example, Hoffman and Sembiate (1975, cited in Nielsen & Beauchamp, 1991) found that even with experience and formal training in movement skill analysis, physical education teachers and experienced coaches were unable to adequately detect error when given a novel skill to observe.

In light of the aforementioned findings it appears that attention directed towards examining error detection capabilities of individuals in relation to motor expertise and the performance of highly complex skills, may prove beneficial on a long-term, broader perspective. If empirical evidence can be procured supporting the notion that expert performers possess a greater capability for detecting errors than novices on a *complex motor skill*, this would open the door for exploration into how error detection capabilities are acquired; what the principles of acquisition are; or which of the various sensory information modalities contribute to error detection and the self-regulatory process (Schmidt, 1987). If procedures can be developed to facilitate the acquisition of error detection capabilities in the educational setting, the learner could provide feedback to him- or herself, even when the coach or instructor is not present, thus enabling the individual to become independent or active in his or her own learning process (Schmidt, 1988).

Statement of Research Question and Purpose of Study

The purpose of this preliminary project was to address the question of whether performers in the final stages of skill acquisition actually display superior judgements of movement production accuracy (error detection) then less skilled individuals on a complex motor task. If skilled performers possess a greater capability for detecting their own errors as compared to novice performers, than individuals possessing superior skill should exhibit a greater correspondence between what they perceive to be occurring and the empirical reality of what is actually occurring.

To examine this notion, three studies were conducted. In an attempt to establish the accuracy and precision of the instrumentation system employed in the latter two studies, Study One was performed to assess the validity and reliability of the measurement device utilised in this project. Studies Two and Three served to investigate the error detection capabilities of skilled and less skilled performers. The latter two studies involved the participation of 40 male golfers (n = 10 low handicapped golfers/study; n = 10 high handicapped golfers/study) and utilised the golf swing as the complex motor task.

In Study Two, golfers were asked to hit three sets of 20 golf balls off a rubber tee using either a driver or a three wood. With information regarding the flight of the ball eliminated, participants were asked to focus on one of the following clubhead parameters during each set: clubface angle (CA), impact point (IP), or clubhead swing path (SP), the order of which was randomized for all participants. After each swing, the participant was requested to verbally report his perceived performance on the parameter of focus (CA, IP or SP) according to a seven choice parameter scale. The participant's perceived score was then compared to a standard (actual score) obtained from the GolfTek Pro V Swing Analyser™. Absolute error (AE) and total variability (E) were calculated for each parameter of focus (CA, IP and SP), and differences between the low and high handicap groups were assessed using independent t-tests ($\propto = .05$). It should be noted that in Study Two, actual performance results were not released to the participant during the testing session.

In Study Three, participants followed exactly the same methods and procedure described above, with one exception. Before each trial set, participants received a calibration session of ten swings where each golfer received actual knowledge of performance regarding the parameter of focus from the experimenter.

Study Delimitations

A number of restrictions were placed on Studies Two and Three. For example, 40 male volunteers were recruited from various golf clubs throughout a major Canadian city and surrounding community. The participant sample was restricted in that study inclusion was based on two criteria: (1) possessing a golf handicap of 10 or below; or (2) exhibiting a golf handicap between 20 and 30. Those individuals possessing a low handicap (≤ 10) were considered to be more skilled than individuals possessing a high handicap (20-30). However, it should be noted that possessing a 10 handicap implies that an individual shoots approximately 10 shots over par on a round of golf. By definition, a 10 handicap does not make one an "expert". Therefore, this study was restricted in scope because the low handicap golfers (handicap range = 0 to 10) were only thought of as being more skilled than the high handicapped golfers, and based on merit, were never referred to as *motor experts*.

Due to the nature of the task, participants were asked to hit golf balls off a rubber tee into a net. A golf swing is a closed motor skill and therefore, the motor pattern is the skill (Starkes, 1993). Based on this notion, the study sample excluded first time golfers and included only those possessing the aforementioned golf handicaps. This was implemented to ensure that performers could reliably reproduce the standardized pattern. This contrasts with an open skill where the "outcome of the movement must be effectively produced and a standardized motor pattern is rarely of help" (Starkes, 1993, p. 6).

Investigation of the movement attributes of the golf swing were constrained to the examination of three dependent variables referred to as clubface aspects: clubface angle (CA), impact point (IP), and clubhead swing path (SP). These three parameters denote the behaviour of the clubface at the moment of ball impact and therefore, interact to directly cause all variations of ball travel and distance. In an attempt to control the experimental setting so that participants were restricted to only sensory feedback produced at the moment of ball impact, flight trajectory and location of ball impact on the net were occluded from participant vision. Further, participants were restricted from receiving knowledge of results (KR) regarding these parameters during the testing sessions of both Studies Two and Three.

Since the Golftek Pro V Swing Analyser™ is an indoor golfing system, testing took place under controlled laboratory conditions rather than the outdoors. Although the laboratory was set up to resemble a golf driving range, participants did not experience intervening environmental variables such as rain or wind, and as previously mentioned, did not receive access to some forms of KR (e.g., viewing flight trajectory of the golf ball, observing the distance achieved, or witnessing the landing point of the golf ball). In addition, participants who had used the GolfTek Pro V Swing Analyzer™ within the last year, or those who may have been able to qualify for the low handicap group in the past, but currently fit the high handicap criterion, were also excluded from the study.

Golf handicaps are designed to represent consistency of one's golf performance and were used in this study as a method of determining skill level of a participant. In essence, the golf handicap is a scoring system based on a player's gross score for a certain number of golf rounds (past and present) and the rating of the course where the rounds were played. As such, it allows players of all levels to compete together on an equitable basis and is a way to assess performance level relative to others. Although an individual's handicap can increase or decrease, it is a useful methodological tool. Due to the large number of golf rounds that go into calculating a golf handicap (e.g., 20 rounds of 18), it is a scoring device that remains relatively stable for extended periods of time.

Study Limitations

In the research literature, the protocol used in this study has been labelled the "expertise approach" (Ericsson & Smith, 1991). In this protocol, a skilled performer in a particular domain is compared to an unskilled performer on a specific component in that skill domain. If the skilled individual is found to be better than the less skilled individual, it is suggested that the task must reflect some knowledge or capability that is possessed by the skilled individual to elicit superior performance. The assumption behind the expertise approach is that the knowledge or capability is *acquired* through experience and training, rather than an *innate* ability possessed by the individual (Allard, 1993). If skilled golfers in Studies Two and Three are shown to be more accurate at reporting their performance, it will be assumed that error detection is an acquired capability rather than an innate ability possessed by the individual.

Another limitation that arises in an empirical study of this nature is that skill and experience are inherently confounded within an individual. It is rare, for example, to find a highly skilled performer who has little experience at the task being studied (Starkes, 1993).

For this project, a motor expert was defined to be any individual who possesses a consistent record of excellence in the golf domain where the outstanding behaviour is attributed to relatively stable characteristics (Ericsson & Smith, 1991). Unfortunately, the existing body of literature pertaining to motor expertise displays a lack of consistency when determining criteria for what constitutes an expert. As Starkes (1993) points out, "in one study "experts", might be movement professionals with many years experience, in another varsity level athletes, and in a third developmental study-12 year olds ranked at a national level" (p. 6). Such an inconsistency amongst the literature makes it difficult to compare, generalize results, and formulate a strong theoretical framework for a thorough understanding of motor expertise.

A fourth limitation surrounds the issue of asking participants to verbally report their performance on a scale. Verbal labelling assumes that it is possible for an individual to detect an error signal, be aware of the *amount* of error, and that the error can be transformed into a reportable form and expressed on a measurement scale.

Finally, it should be noted that this study was based on the philosophical assumption that individuals take in information from the environment, this information is processed or transformed, and finally, after a complex chain of processing activities, a response or output is made. Hence, this cognitive approach is referred to as the information-processing perspective, and suggests that humans are independent of their environment and actively process information (Slife & Williams, 1995). Cognitive theory emphasizes the role of structures and processes that lie beneath the surface for the explanation of behaviour. Cognitive processes subserve action by modifying and selecting the information that gets into the system and what information passes through each processing stage (Shea et al., 1993). As such, this approach assumes an "executive level" of functioning, whereby control of movement is carried out by what has traditionally been referred to as a "homunculus" or "little man inside the head" (Turvey, Fitch, & Tuller, 1982, p. 239), giving rise to models of movement that are hierarchical in nature. As a consequence of stage processing, two individuals rarely respond to the same stimuli in an identical manner; rather, the proficient execution of a simple or complex movement requires an individual to consider the current circumstances (e.g., the speed or flight path of the ball), as well as retrieve information stored in memory to plan and execute the movement. Thus, control of performance in a motor situation is achieved by accessing a motor program described as an "internal representation that prescribes the action of the effector components underlying the movement" (Schmidt & Fitzpatrick, 1996, p. 105). Two basic assumptions of the information processing approach, are "that (a) some kind of symbolic representation of the intended movement is necessary to allow the mind, body, and environment to interact, and (b) the body is essentially subservient to the mind" (Abernethy, Burgess-Limerick, & Parks, 1994, p.188). This type of cognitive theory contrasts sharply with the philosophical assumptions of ecological psychology. For example, proponents of the ecological perspective reject the notion of a mind body separation and posit an animal-environment reciprocity, which proposes that information is directly acquired from the environment and immediately becomes meaningful to the performer. In essence, this perspective suggests that movement systems are self-organizing whereby a response action emerges from a heterarchical model and control is maintained through the interaction of various variables within a system. As such, movement regulation can best be understood in terms of physical laws and principles within the dynamics of musculoskeletal structures and couplings, rather than "some higher order executive prescribing instructions for control" (Chua & Weeks, 1997, p. 375). The ecological approach inherently denies the necessity of symbolic representations and the involvement of mental processing to achieve a movement response.

CHAPTER TWO

REVIEW OF THE LITERATURE

The purpose of this chapter is to provide a detailed review of literature pertaining to the topic of error detection capability and general issues that relate to error detection. The chapter begins with a section illustrating self-regulation and its link with cybernetics or closed-loop perspectives of behaviour. Most importantly, this section will define sensory feedback and discuss its crucial role in the detection of error. The second section serves to highlight fundamental error detection components that are already inherent within the framework of traditional theories of motor learning. This discussion will be followed by a section devoted strictly to examining the existing body of literature which addresses the idea of an error detection capability within their investigations. Finally, a discussion relating the importance of perception to the study of error detection will be presented.

Self-regulation, Cybernetics, and Feedback

During the performance of a complex motor skill, individuals are often left to rely on their own devices to cope effectively and independently in numerous situations. Fortunately, it has been acknowledged that human beings possess a unique capacity to exert extensive control over their own inner states, processes, and responses (Bandura, 1977). This quality, referred to as self-regulation, accompanies the performance of a cognitive task and, "allows an individual to control, govern or direct his own action through self-imposed rules or regulations that better adapt his performance to different circumstances and surroundings" (Ferrari et al., 1991, p. 139). Such regulatory control includes rules for planning, monitoring, and verifying performance which may be applied before, during, or after an individual's action. Self-regulation, therefore, is "dynamical and cyclical" (Kane, Marks, Zaccaro, & Blair, 1996, p. 37) and, in a broad sense, refers to "any effort by a human being to alter his own responses" (Baumeister et al., 1994, p. 7). Selecting, modifying, or maintaining a response occurs each time an athlete steps into the performance ring. The bobsled driver, for example, careening down a course at alarmingly dangerous speeds, relies on his capability to detect deviations in his course and make adjustments with the finest precision if he is to guide himself and his teammates safely down the course.

All human motor responses of this nature are based on the simultaneous integration of many parts working collectively, the success of which is largely dependent on how well the parts work together (Schmidt, 1982). One fundamentally important control system that has been identified for the study of human motor response is the closed-loop system and has commonly been referred to as the cybernetic viewpoint. In the past, principles of cybernetics have been applied to electronic, electromechanical, and biological systems, but were potentially applicable to any kind of self-regulating system. Recently, control principles have been examined as to how they underlie behavioural self-regulation. In fact, much of the research and theories of self-regulation in the educational literature have borrowed extensively from a closed-loop view of behaviour (Baumeister et al., 1994; Carver & Scheier, 1981, 1982; Mithaug, 1993; Schunk & Zimmerman, 1994; Zimmerman & Schunk, 1989).

During the learning and/or performance of a motor skill, there is a great deal of information that becomes available as a result of the performer's actions. Various sense modalities (i.e., proprioception, vision, audition) may act exclusively or in overlapping fashion to offer information about the nature of the performance, as well as the results of the performance. This feedback is perhaps the most important concept in cybernetics and is essential for the processing of errors and the self-regulation or control of movement.

Feedback is generated when some of the output from the system is isolated and the information is fed back into it as input. The feedback is then compared to a reference value constituting the goal of the behaviour, which compares the actual response outcome (sensed value) to the desired response outcome (standard of comparison). If a discrepancy occurs between the two, an error in movement has thought to have occurred. This information is then given to an executive level, and decisions can be made as to the response strategy best suited to reduce the error to zero in subsequent performance. Thus, adjustments are made according to the detection of discrepancies within the system. This procedure is conducted until there is no discrepancy between the actual state and desired goal. In essence, this "discrepancy-reducing" or "negative" feedback loop, encourages and permits the detection and correction of errors by informing the performer as to the nature and extent of the correction needed (Schmidt, 1982; Singer, 1975, 1980). As such, the principles of cybernetic control are self-regulatory principles.

It is important to note that a key assumption of this model is that self-regulatory behaviour is first and foremost a function of the perception of a discrepancy between a goal state and a current state (Mithaug, 1993). Perception implies the process of interpreting or providing meaning to sensory information (Magill, 1993), and in some situations, the information received from intrinsic feedback may be easily perceived and evaluated by the learner (e.g., when a figure skater falls he/she undoubtedly *feels* that an error has been committed by virtue of landing on a cold, hard ice surface). However, due to the complexity of many motor skills, there are some aspects of intrinsic feedback that are not easily perceived and acute awareness of these aspects develop as a function of practice (e.g., a diver learns to sense whether or not his/her body is bent while rotating in the air). As performers gain the ability to execute a response without having to concentrate on the motor act itself, performers are better able to attend to finer feedback details to permit optimal performance.

In the motor learning literature, there has been some controversy surrounding expert performance and the way in which sensory information may be handled by skilled performers (Starkes, 1993). For example, Fleischman and Rich (1963) proposed a theory that addresses the relative importance and use of exteroceptive (spatial-visual) and interoceptive (proprioceptive) cues in the early and latter stages of motor skill learning. This theory suggests that sensitivity to exteroceptive cues plays a crucial role in the early stages of skill acquisition. Errors committed in the beginning stages tend to be large, and therefore, spatial cues are predominately utilized by the learner. As the performer gains task proficiency, errors tend to become smaller in nature and finer motor adjustments are required to improve performance. At this stage, spatial cues are less effective in facilitating precise motor control and there is a shift from the eminent use of exteroceptive cues to the use of proprioceptive cues for continued perceptual-motor learning. In contrast to the idea that learning shifts from one source to another, a different approach suggests that movement learning is relatively specific to the feedback condition under which practice occurs. Proponents of this perspective advocate that as learning progresses, movement-relevant information is integrated into a sensorimotor representation by the performer that is specific to the learned task. The more practise one has using a particular source of feedback during skill acquisition, the more important that source of feedback becomes for the control of the movement. Part of becoming skilled, therefore, may involve learning to handle task specific sensory information more effectively (Elliot & Jaeger, 1988; Proteau, Marteniuk, Girouard, & Dugas, 1987; Proteau, Marteniuk, & Lévesque, 1992). For example, Proteau et al. (1987) have shown using a manual aiming task, that the elimination of visual feedback after participants had experienced moderate practice with vision (200 trials) rendered a deterioration in performance. Furthermore, an even greater deterioration in performance occurred when visual feedback was terminated after participants had practised (with vision) for an extended period of time (2 000 trials).

Although each of the aforementioned theories present a different perspective for understanding how task specific sensory information is handled by skilled performers, both of these theories acknowledge the importance of feedback to the successful execution of a motor task and *do not* assume that automated actions no longer require feedback. When performing complex motor movements, even individuals who are highly skilled do not always produce the desired consequences. For instance, how many times has an elite figure skater switched from a triple to a double in the air or how often does a curler elect to hold his or her rock all the way to the hog line when he or she has driven too hard out of the hack? Such an alteration in performance clearly indicates that humans must possess a mechanism to detect the occurrence of errors so the error can be immediately corrected by subsequent actions. Furthermore, performance modifications also imply that learners must be aware of their errors at some level if they are to detect or learn from them (Ohlsson, 1996). In fact, there are those who suggest that it is the detection of performance errors that plays a key role in the acquisition of skilled motor performance. Ohlsson (1996) proposes that learning events may be triggered by the discovery of errors. Learning, defined as the rate at which an individual changes, is suggested to be a function of the number of errors that are detected by the performer. Early in skill acquisition, novice performers display the tendency to make a large number of errors per trial which tend to be gross in nature. However, as mastery is approached, rate of change decreases because skilled performers make fewer errors per trial. Ohlsson (1996) suggests that a negatively accelerated learning curve highlights the importance of error discovery and shows that if performance errors are not discovered, learning is impaired.

Motor Learning Theories

In the motor learning literature, the presence of an error detection mechanism has long since been acknowledged as a factor in the acquisition and control of movement by such classic cognitive theories as Adams' (1971) closed-loop theory and the motor programming and schema theories of Schmidt (1975, 1980). Central to both of these theories is the idea that feedback generated by a performer's actual movement is compared against an internal representation which serves as a standard of reference.

Closed-loop Theory

Adams' (1971) feedback-based theory postulates that learning is a product of two associative memory states. The first state, termed memory trace, refers to the learned capability for selecting and executing a motor response and is found in many theories of motor learning. However, the conceptualization of a reference standard distinguishes this theory from others and is identified in Adams' second memory state labeled as the perceptual trace. In essence, the perceptual trace is an internal representation of response-produced feedback consequences that directs subsequent action by evaluating the correctness of a response executed by the memory trace. Adams claimed that all movements are made by comparing the ongoing feedback from the limbs during the movement to a reference of correctness developed as a result of practice. The formulation of the internal reference of correctness is based on the notion that sensory information (i.e., proprioception, vision, audition) available during a movement, leaves a trace or "image" that is stored by the learner from each movement response. As a learner becomes more proficient at a skill, discrepancies between the trace and criterion will decrease and the distribution of these traces will gradually represent the feedback qualities of the correct response. As such, when a strong reference standard has been established, the perceptual trace can serve as a reliable source of error information affording individuals the opportunity to recognize their own performance errors without a reliance on external sources for the acquisition of knowledge. Adams terms the capability of a learner to discern a difference between the feedback received and the perceptual trace as subjective reinforcement. Thus, a key component of Adams' theory is the notion that the development of a mechanism to detect error is in large part a function of the quality of the sensory feedback received during the acquisition of a skill. As an individual's reference of correctness becomes strengthened over practice, incoming sensory information should also be evaluated more effectively. Therefore, past research studies have attempted to manipulate the sensory information available and the quality of information received to determine the development of proficiency in the evaluation of error (e.g., Adams, Goetz, & Marshall, 1972; Adams & Goetz, 1973; Schmidt & Wrisberg, 1973; Adams, Gopher, & Lintern, 1977). Studies provided by Adams and his colleagues (Adams et. al., 1972, Adams & Goertz, 1972; Adams et al., 1977) provide evidence that an increased quality of visual, auditory, or proprioceptive feedback leads to greater efficiency when performing linear positioning movements. Further, the ability to regulate movement is related positively to amount of experience with feedback in the task. The greater number of trials and the more feedback available to the learner, the better the evaluative mechanism becomes.

Schema Theory

Borrowing heavily from Adams, Schmidt (1975) formulated a theory that elaborates on error-detection mechanisms from a slightly different perspective. After a movement is executed, four types of information are stored by the leaner: (1) the initial conditions; (2) the response specifications; (3) the response outcome; and (4) the sensory consequences. From this information, two types of relationships (or schemata) are developed. Analogous to the role played by the memory trace in Adams' theory, the first schema is concerned with the production of the movement and is classified as the recall schema. As such, it enables the performer to select and execute the required parameters for the movement. The second relationship, the recognition schema, is responsible for evaluating response-produced feedback and informing the learner about the direction and amount of an error. Because the recognition schema represents the relationship between the initial conditions, response outcome, and sensory consequences, the learner can estimate the "expected sensory outcomes" (Schmidt, 1988, p. 486) of a movement after a desired outcome has been selected and initial conditions determined by the recognition schema. During and/or after a movement has been executed, the expected sensory consequences are compared against actual response feedback (e.g., proprioceptive and exteroceptive feedback). Any discrepancy between the expected and actual sensory consequence produces an error in movement response giving rise to a sensory signal that is fed back to the schema so that adjustments can be made by the performer to reduce the error to zero. This error is also fed to an error labeling system which converts a raw signal into a reportable form. Schmidt identifies the labeled error signal as subjective reinforcement and is proposed to be a third schema. The labeled error plays an important role in learning, yet, it has received little attention in the motor behaviour literature (Swinnen, 1988). The capability of labeling error signals may prove to be central in facilitating learning independence and the rationale for such a notion is clearly evidenced in the following statement by Schmidt (1988):

> The labeled error signal is termed subjective reinforcement and can serve as a substitute for Knowledge of results (KR), providing outcome information that can update the recall schema. Thus, the learner builds an error-detection mechanism

> that helps him/her to perform movements successfully when KR is no longer present (p. 239).

Whether it is the notion of a perceptual trace or recognition schema, both theories imply transition from reliance on externally-provided feedback to the development of an internally-derived mechanism that can maintain and even improve performance in the absence of augmented feedback. Although empirical evidence has constrained itself to simple, slow-graded or rapidly-executed, linear positioning tasks, a characteristic of expert performance might be the capacity to detect error and needs to be examined more closely from a motor learning and control perspective.

Error Detection Capabilities

Although Adams' (1971) closed-loop theory has implied its applicability to other response classes, Adams deliberately limited his theoretical predictions to data dealing with slow positioning tasks. In the early seventies, a number of researchers (e.g., Newell, 1974, Newell & Chew, 1974, Schmidt & White, 1972; Schmidt & Wrisberg, 1973) examined the acquisition of error detection capability using rapid response tasks. By employing the use of rapidly-executed pre-programmed tasks (e.g., a short linear distance of 10-15 in. with a movement goal time of 150-200 ms), the experimenter can eliminate the potential use of feedback control during the response of the movement. Research findings indicate that an important interaction exists between the capability of subjects to detect their own errors and the movement time of the response to be produced (Schmidt, 1987) such that the contributions made by error detection mechanisms are fundamentally different between slow and rapid types of responses. In a slow movement, for example, it appears the process of error-detection may lead to the continuation of an action. Learners performing a positioning task can evaluate the intrinsic feedback against the reference of correctness and make the required adjustments *during* the movement if an error is detected. In a rapid movement, the response is over before response-produced feedback can be used. Error detection capabilities are not used during the execution of a movement for control; rather, the individual must evaluate his/her performance *after* the response has been made. This 'knowledge of response correctness' (Schmidt, 1988, p. 84) can then be used for the execution of the next response.

Evidence for the development of an error detection mechanism over practice in a rapid response task was first reported by Schmidt and White (1972). Performing a ballistic timing task, participants were asked to move a hand-held slide a linear distance of 9.5 in. in 150 ms for 170 trials over a period of two days. After each trial and before individuals were provided with their actual score (objective error), they were asked to verbally estimate their movement time in milliseconds (subjective error). To determine if an improvement in a participant's error detection capability occurred with practice, the difference between the subjective and objective error scores was calculated, and within-subject correlations were computed between the two error scores for each block of ten trials. The findings revealed that as practice continued, a decreasing difference emerged between the judged and actual score, and by the experiment's end, indicated a mean difference of only seven ms. In addition, there was a continuing correspondence between a subject's estimated error and actual error with nearly maximal positive correlations by the end of the practice session even with the withdrawal of KR. Participants showed no deterioration of performance and continued to improve in the absence of KR. However, it was also shown that if KR was withdrawn early in task learning, before the development of a strong response-recognition mechanism, a decrement in performance materialized. Such evidence indicates that as learning progresses, participants become increasingly sensitive to their sensory errors through information provided by KR, and formulate a method with which they can use to evaluate their performance on the previous trial. As the perceptual trace becomes strengthened and response evaluation can be carried out with an increasing degree of accuracy, participants are able to maintain or improve performance without the input of KR. Corresponding findings have been presented supporting the development of error detection capabilities by Schmidt and Wrisberg (1973, Expt.1), Newell (1974), and Newell and Chew (1974) using similar short, fast, linear timing movements (26 in./200 ms, and 24.03 cm/150 ms, respectively). In these studies, subjective estimates were also used to assess the strength of the error-detection mechanism; however, in the latter two studies, the difference between the objective and subjective error was used as the index of error-detection capability.

In an attempt to examine the merits of both Adams' and Schmidt's viewpoints, the aforementioned studies have all required participants to actively generate movements within their experimental protocols. Evidence for acquiring error detection capabilities through passive sensory experience has also been reported in the motor behaviour literature. Zelaznik and Spring (1976) and Zelaznik, Shapiro, and Newell (1978) developed an alternative paradigm based on Adams' notion that *any* experience with the sensory consequences of a response (whether it be active or passive) should provide a reference of correctness for a learner. Therefore, it was hypothesized that the capacity to develop an error detection mechanism should not be dependent on actively performing the movement. Using a loudspeaker, Zelaznik and Spring (1976) asked one group of participants to experience the auditory sensory consequences of another participant actively practicing a ballistic timing task (30.48 cm in 150 ms). Without seeing the apparatus or the active performance of the task, participants from the "auditory group" were then asked to perform the criterion movement in the absence of KR. In Zelaznik et al.'s (1978) study, participants were asked to listen to a tape recorded series of sounds of the slide moving along the trackway before performing the criterion movement (10 cm in 130 ms) in the absence of KR. In both studies, findings clearly revealed that these participants exhibited remarkedly lower scores in the initial no-KR trials (Zelaznik & Spring, 1976) and in fact, continued to improve in the absence of KR (Zelaznik et al., 1978). It was argued that performance could not improve without the presence of KR unless the sensory information passively experienced prior to an overt response developed an error detection mechanism by "establishing a pre-practice reference of correctness" (Schmidt, 1982, p. 489). Furthermore, it was suggested that participants were able to transform the auditory feedback into a visual image of the movement and used it in active practice as a basis for error detection and correction. Within the educational setting, the "Suzuki method" for teaching young students to play the violin is one such procedure developed to help learners establish detailed references of correctness (Schmidt, 1988). In Suzuki music lessons, participants receive experience in listening to music to develop a memory of how a properly played piece should sound. Only after receiving extensive exposure to the piece are pupils permitted to play the musical arrangement. Presumably, the reference of correctness established by the pupil's listening experience is used to detect and correct his/her own errors in actual practice. Because the reference of correctness is at the heart of the closed-loop system and constitutes the basis for an error detection mechanism, it is essential to develop procedures to help learner's establish a pre-practice reference of correctness through both passive and active modes of learning.

Interestingly, Schmidt and White's (1972) study is commonly cited as evidence for differences in error detection capabilities between expert and novice performers (Abernethy et al., 1993). However, the applicability of such research findings is limited in that it is constrained to simple, linear-positioning tasks which require participants to move their hands a specified distance. Based on the conceptualization that learners mentally compare intended and perceived outcomes of actions and that discrepancies contain information for the performer (Adams, 1971; Schmidt, 1975), a complementary approach would be to acquire empirical evidence pertaining to the acquisition of complex motor skills.

Self-perception of Error

Errors are inappropriate actions committed while performing a task (Ohlsson, 1996) and may arise as a consequence of incorrectly evaluating the environmental display. This directs the individual towards the development of an inappropriate plan of action, incorrect application of movement dynamics (e.g., force, velocity), or misperception of a situation, all of which leads to inappropriate motor behaviour (Rose, 1997). In the past, research examining the mechanisms that enable people to detect and correct their own errors have primarily focussed on cognition with a lack of concern for the motor component of tasks; whereas, proposed computational models of cognitive skill acquisition have placed an emphasis on successful actions rather than errors (e.g., rule composition, Frensch, 1994). Furthermore, when examining the nature of errors, research has focussed on the classification of errors and the condition under which different classes of errors occur (Ohlsson, 1996). For example, in the motor behaviour literature, two distinct types of errors are thought to be produced by the motor system, each of which utilise feedback in different ways. The first type of error, referred to as an error in response selection, pertains to the selection of an inappropriate response in a movement situation. A response selection error occurs when a performer selects the wrong pattern of action for the current situation (e.g., a baseball player attempts to steal second base rather than stand on first). To correct a response selection error, the performer must issue a new motor program to achieve the environmental goal. The second kind of error, referred to as an error in response execution, occurs when an appropriate movement pattern is initiated but an unexpected event in the environment disrupts the action (e.g., an unexpected shift of wind occurs while a dancer is performing on an outdoor stage). In this type of error, the environmental goal can still be achieved using the original motor program provided some adaptation to the program occurs to compensate for the unexpected disruption (Schmidt, 1988).

Although it is important to understand the different types of errors that may exist and the condition under which distinct classes of errors occur, past theories have neglected to include a framework for how people learn from their errors. Recently, Ohlsson (1996) has proposed a theory of how people detect and correct their own performance errors. The basic principles of his theory suggest that

> (a) errors are caused by overly general knowledge structures;
>
> (b) error detection requires domain-specific declarative knowledge;
>
> (c) errors are corrected by specializing faulty knowledge structures so they become active only in situations in which they are appropriate; and,
>
> (d) errors are experienced as conflicts between what the learner believes ought to be true and what he or she perceives to be the case
>
> (Ohlsson, 1996, p. 242).

The latter notion pertaining to perception is of particular importance to this project and the context for which error detection is being examined. Since we possess a limited processing capacity, performers cannot attend to all stimuli in the environment. To successfully organize and execute a movement pattern, the performer must identify and selectively attend to only those aspects of the skill and environment that are directly relevant "or regulatory" to the performance (Gentile, 1972). Therefore, "particular actions are neither correct or incorrect in themselves" (Ohlsson, 1996, p. 245) but become recognized as errors in only certain circumstances. Thus, the quality and validity of a response are largely dependent on the quality of interpretation, inference, or meaning bestowed to the sensory information by perceptual processing. When a stimulus in the environment triggers a sensory receptor (e.g., the eyes), a signal is transmitted to the brain. As such, sensory receptors play a passive role of receiving and transmitting, and the information it sends does not reach the brain pre-analysed. When information reaches the cortex of the brain, it must be identified and integrated with other bits of received or stored information so that an executive level decision can be made and a response action carried out by the performer. In essence, perception serves to inform the mind about the outside world (Hofsten, 1987), and is the process of organizing, interpreting, and labelling incoming sensory information to provide meaning (Kerr, 1982; Magill, 1993). Consequently, perceptual processing has a profound influence on the quality and validity of an action response.

Variability in perceptual interpretation or recognition of errors between individuals may be accounted for by differences in past experiences and the possession of domain-specific knowledge. For example, when hitting a golf ball, the golfer may detect the occurrence of an error by witnessing his ball slice or curve violently to the right after being struck. If a golfer knows that a slice is caused by an outside-to in swing path or an open clubface at impact, the golfer will derive meaningful information to correct the detected error on a subsequent swing. However, if the golfer has no pre-existing knowledge about a slice or what causes it, he will continue to swing outside-in or with an open clubface, gleaning no meaningful information from the ball's flight trajectory. Therefore, deriving meaning for the detection and correction of errors in a motor situation requires some type of mental representation or pre-existing knowledge stored in memory for an accurate interpretation of the environmental circumstances. As Fodor and Pylyshyn

(1981) state, "What you see when you see a thing depends upon what the thing you see is. But what you see the thing as depends upon what you know about what you are seeing" (p. 189).

One fundamental component for producing a quality action response appears to be the ability to recognize the existence of a discrepancy between actual and intended states of the environment. Thus, one question that must be asked in empirical research, is to "what extent does an individual's spatial thought or perception succeed in representing the world out there?" If judgements of movement reproduction accuracy are to be made (error detection), then what an individual perceives to be occurring and the empirical reality of what is actually occurring must correspond. Accurate frames of reference are essential if replication attempts are to be compared and evaluated against appropriately by the learner. Unfortunately, a limitation of motor learning theories such as Adams' (1971) closed loop hypothesis is that it focuses on discrepancies between actual and intended limb trajectories. Such a theory must also include errors that are defined as discrepancies between actual and intended states of the environment (Ohlsson, 1996).

In the motor behaviour literature, empirical evidence suggests that the accuracy of one's estimate of performance may depend on the complexity or nature of the task. For example, Schmidt and White (1972) found that participants were able to estimate their errors within an average of seven ms of their actual time. However, Schmidt and Wrisberg (1973) reported larger mean differences between objective and subjective times (around 12 ms) than Schmidt and White's (1972) data. It was suggested that the difference was due to the longer movement distance (26 versus 9.5 in.) and criterion time

(200 versus 150 ms) that the participants were asked to perform in their study. This subtle finding has important implications as it suggests when participants are required to execute more complex movements, they may experience greater difficulty when asked to accurately estimate their performance on a criterion. Difficulty in accurate error estimation has also been demonstrated more recently while executing simultaneous movements. For example, when Sherwood (1998) asked participants to perform a rapid bimanual aiming movement over different distances, spatial assimilation occurred with the shorter distance limb displaying the tendency to overshoot when paired with the longer distance limb. Consequently, participants displayed difficulty detecting the spatial assimilation and exhibited an inclination towards underestimating their error. However, if a participant was prompted to focus on only one limb in a bimanual condition, assimilation effects were reduced and an improvement in the accuracy of participant error estimation occurred. This finding implies that a lack of error detection capability may be due to the complex nature of the task demonstrated by the participant's difficulty in attending to both limbs at one time. As the number of stimuli or events a performer must contend with increases, it is possible that each stimulus becomes less discriminable from the other as a result of an increased perceptual uncertainty in response selection (Shea et al., 1993).

Since it is suggested that various sense modalities may act in overlapping fashion to offer information about the nature of a motor performance, perceptual accuracy may also depend on various perceptual systems functioning in a collaborative manner. One example of this notion pertains to findings rendered by Smyth and Marriott (1982) while investigating the interaction of vision and articular proprioception in simple one-hand catching. Smyth and Marriott (1982) postulated that preventing sight of the catching hand should not affect the accuracy with which one catches the ball since articular proprioception is considered to provide accurate information regarding limb position, especially in ball skills where the eyes are thought to track the ball. However, Smyth and Marriott (1982) found evidence suggesting this not to be the case. Although participants were permitted to visually track the ball's flight, the number of balls dropped increased substantially when the participant was prevented from seeing the catching hand. Further analysis revealed that participants were unable to place their hand correctly in the line of ball flight and therefore, errors occurred as a result of hand positioning rather than timing of the grasp. Most relevant to this discussion, however, was the finding that participants who could not see their hands while catching could not accurately maintain their estimate of the position of tactile stimuli on their arm. Smyth and Marriott (1982) speculated that felt position of the hand could not be accurately maintained without vision because calibration of the proprioceptive system requires constant visual updating.

Accuracy in performance estimation may also depend on one's ability to transform an error signal from raw sensory input into a reportable form. Schmidt (1975) has labeled this ability as subjective reinforcement, and suggests that it is a learned phenomenon. This notion is supported by evidence provided by Newell and Boucher (1974). In this study, Newell and Boucher (1974) asked blindfolded participants to move a linear slide twenty times to a stop and verbally estimate the movement distance. The stop was then removed and each participant was asked to reproduce the movement in a single criterion test trial and verbally estimate movement distance. One group estimated the distance in inches, while the other group answered in millimeters. It was found that both groups received the same raw sensory information to formulate their estimates since there was no difference in actual movement error between the two groups. However, estimation errors were significantly greater than each participant's respective movement error and the group that was asked to guess in inches displayed nearly half the error that was displayed by the participants estimating in terms of millimeters. One leading interpretation suggests that the participants were more familiar with the inches scale, and therefore, could attach a label to the feedback with greater accuracy. As movements become more complex (e.g., participants are asked to execute a golf swing rather than a simple ballistic task), individuals are faced with a larger number of options. Thus, recognizing an error signal may become more of a challenge. Until domain-specific knowledge is acquired, individuals may exhibit difficulty in labeling and estimating the accuracy of their performance and may in fact, fail to detect the occurrence of an error. Therefore, further empirical studies are needed to determine whether highly skilled performers display a greater degree of accuracy than less skilled individuals when comparing subjective reports to actual (objective) performance measurements.

Of additional interest, Newell (1974) also reported that in the beginning, even though KR was provided to participants and they were well aware that they had produced an error, they encountered difficulty processing KR into an appropriate response strategy. Such a finding may be applicable to discussion involving the execution of gross motor responses. When performing a gross motor skill, most learners seem to be able to acknowledge when they have made an error. For example, if a skater falls onto the ice surface while attempting to land a jump, they will without doubt acknowledge the fact that they have committed an error. In fact, they may even be able to identify the source of their error (e.g., I over-rotated in the air and could not plant my foot in time). However, the problem may center around not knowing the response strategy needed to correct it or the individual may lack the knowledge to translate this correction plan into physical movement. In the literature, it is suggested that individuals possessing motor expertise seem not only to acquire skill but declarative knowledge during their apprenticeship period (Ohlsson, 1996). Perhaps then, the difference between an individual who can successfully execute the jump and one who cannot, is that the proficient performer is capable of using the information provided by his or her sensory system (self-regulatory awareness) to perform the skill successfully. In contrast, perhaps the novice performer is either unaware of, or unable to use, the information provided by the sensory system. When declarative knowledge is missing, he or she, in turn, develops a dependency on augmented feedback to guide his or her actions (Buekers & Magill, 1995).

CHAPTER THREE

THE GOLF SWING

The motor skill utilized in this project was the golf swing. The purpose of this chapter is to familiarize the reader and provide an opportunity to obtain domain-specific knowledge regarding key elements of the golf swing before entering the study methodology and discussion sections of this thesis. The first section will outline the golf swing in traditional motor learning terminology, while the second section will focus on quantification issues. Most importantly, the latter discussion, will define and discuss the three clubface factors isolated as dependent variables in this study, and describe how they interact to produce various flight characteristics of the golf ball.

Classifying the Golf Swing

In the motor behaviour field, a variety of organizational schemes have been developed for the classification of motor skills. Considering the breadth and diverse array of existing motor skills, classification systems enable researchers to make generalizations for tasks or movements that possess common or similar components. Classic classification schemes involve discussion around the precision of the movement (gross / fine dimension), the beginning and the end of the movement (discrete / serial / continuous dimension), and the stability of the environment (open / closed dimension) (Magill, 1993; Schmidt, 1988). As such, the golf swing can be discussed with respect to these organizational themes.

When executing a golf swing, there is a distinct beginning and end point. The swing action is initiated as the clubhead is swept up and away from the ball in the player's backswing. From the top of the backswing, an unwinding of force occurs as the clubhead is swung in a downward arc to make contact with the ball. Although there is a deceleration of force after the clubhead has contacted the ball, the path of the clubhead continues through the ball and completes the arc of the swing to finish the stroke with a follow-through. As such, the golf swing is a discrete motor skill. Furthermore, the movements that comprise the motor skill must be performed in a specific order for proper execution (backswing ⇨ downswing ⇨ follow-through). Smooth co-ordination of the large musculature is being used to execute the movement, and is therefore, more closely related to the gross end of the classification continuum. This contrasts with a fine motor activity (e.g., writing), where control of the small muscles of the body are required to achieve the task goal. And finally, the golf swing anchors itself towards the closed motor skill end of the continuum. When a golfer begins a hole, the pin (target) does not move from its location. Further, golf is a closed skill as the action is self-paced. The environment waits to be acted upon which implies that the performer initiates the action at his or her own will. This is converse to an open skill where the performer must act according to the action of the object or an unstable, changing environment. An open skill is externally-paced since the performer cannot initiate the action at his or her own will (Magill, 1993; Schmidt, 1988). In essence, the golf swing is a discrete motor skill that takes place in a relatively closed environment and requires the smooth execution of the large musculature for successful execution.

Quantifying the Golf Swing

A common methodological problem that faces researchers investigating the acquisition of, or the perceptual and cognitive issues surrounding skilled performance is how to quantify skill when assessing motor expertise (Carnahan, 1993). In many settings, a judgement regarding what constitutes a skilled performance is generally based on the final result of the movement. For example, the individual who can successfully complete the greatest number of rotations in the air, run the fastest, or consistently deliver a curling rock closest to the button on a final shot, is often regarded as being the most skilled. As such, performance level in laboratory settings has most commonly been delineated by measures that report on the end result of an action (e.g., reaction time, movement time, force output), rather than the movement pattern that produced the motor output. In an attempt to more fully describe the movement characteristics of a variety of skilled performances, researchers have recently begun employing measurement techniques (e.g., kinematics) designed to capture the moment-to-moment control of movement. Considering a movement goal may be attainable through the implementation of a variety of solutions, such a shift in research focuses provides valuable insight into the execution processes of skilled movement. Further, it plays a crucial role in understanding closed-skill activities such as dance or gymnastics where "the actual form of the movement is the main objective of the skill" (Carnahan, 1993, p. 36). In light of this discussion, it becomes necessary to establish the approach that will be used to quantify the golf swing in this project. The following section will discuss three fundamental clubface factors, as well as describe the importance of these movement attributes to the execution of a successful golf swing.

Isolating Clubface Factors

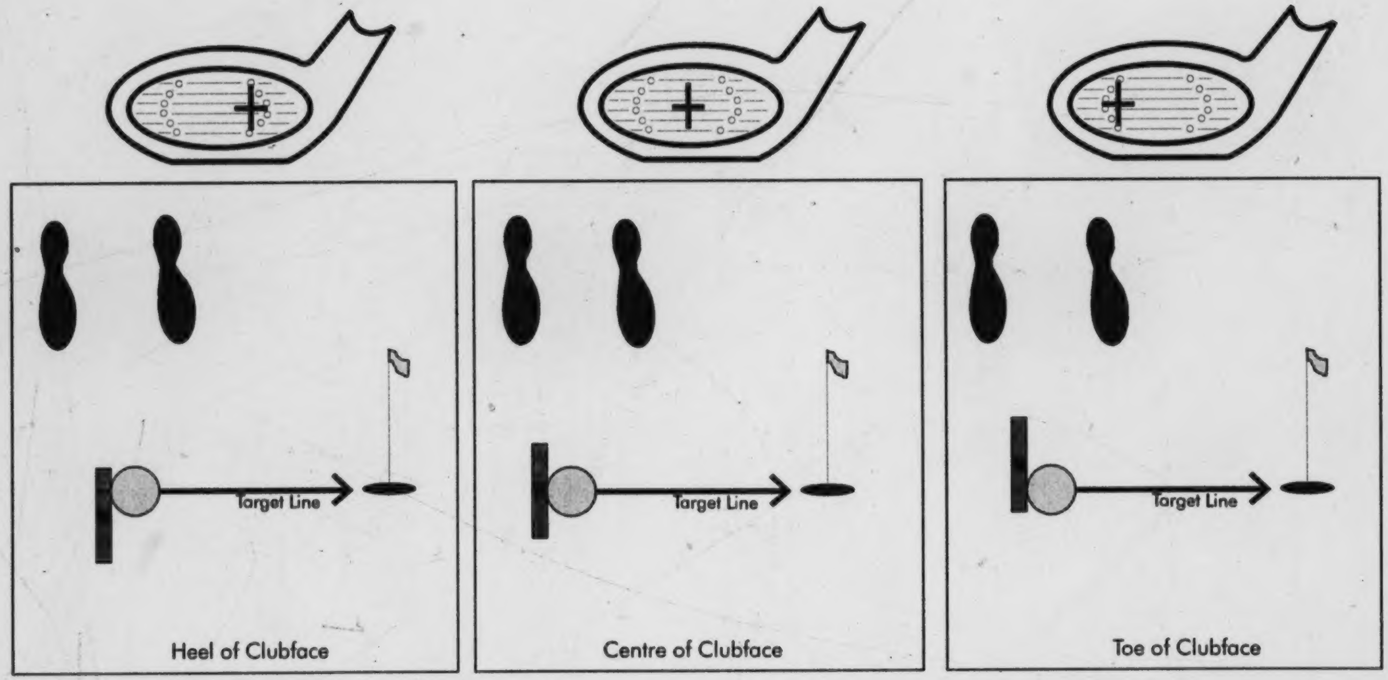
Flight direction and distance of ball travel, is largely established by the position and movement of the clubface at ball impact. In essence, the golf ball can only behave the way the clubface tells it to during swing execution (Dawkins, 1976). Laws of mechanics dictate that regardless of an individual's personal style, one cannot achieve consistency or accuracy when shot making without possessing good control over the position and movement of the clubface at the moment it contacts the ball. Accordingly, a mishit or "ball not flying where it is meant to" (Cochran & Stobbs, 1968, p. 112), can only result from one of, or more commonly, a combination of, the following three antecedents:

> 1. Hitting the ball at a point other than the centre of the club, an off-centre impact.
> 2. Swinging the clubface through the ball in a direction other than along the chosen line of aim, an off-line swing.
> 3. Hitting the ball with the clubface aiming along a different line from that through which the clubhead is being swung, a face off-line to swing.
>
> (Cochran & Stobbs, 1968, p. 112)

Therefore, one way to define movement attributes of a successful golf swing, is to isolate and examine the three distinct clubface factors of angle, travel path, and impact point. A description of each clubface aspect and how each of these parameters relates to one another in determining ball travel is provided below.

Impact Point (IP). Impact point refers to the place on the clubface that meets the golf ball at contact and is one of the factors responsible for the distance a ball travels. When the clubface meets the ball, energy generated by the swing is transferred to the golf ball. The greatest potential for energy transfer occurs when the ball is hit on the 'sweetspot' or the centre of the clubface. However, improper clubface position can occur both forward, toward the toe of the clubface, or aft, toward the heel. When an off-centre hit occurs, the part of the clubface that strikes the ball gives rather easily and turns around its centre of gravity. Such a twisting of the clubface results in a loss of power, and the ball leaves the clubface with less speed than if it had been struck from the centre of the clubface (Cochran & Stobbs, 1968). The more off-centre a hit is, the less distance the ball will travel since less energy can be transmitted to the ball (Dawkins, 1976). For example, hitting the ball one inch off centre towards the toe will result in approximately 12% less distance, while hitting the ball one inch on the heel will result in about eight per cent less distance (GolfTek, 1998). In order to consistently achieve maximum flight distance, the ball must be struck with the 'sweetspot' of the clubface on each and every swing executed. Centre and off-centre variations in impact point are illustrated in Figure 1.

Clubface Angle (CA). Clubface angle is the direction in which the clubface is facing as it meets the ball (Dawkins, 1976). As the clubface moves along its line of travel, it may be squarely facing the direction it is travelling, or it may be angled to the right or left of this direction. In order to develop proper release and timing when the clubface contacts the ball, the face should be as "square" as possible upon impact. Swing problems


Target Line
Target Line
Target Line

Heel of Clubface

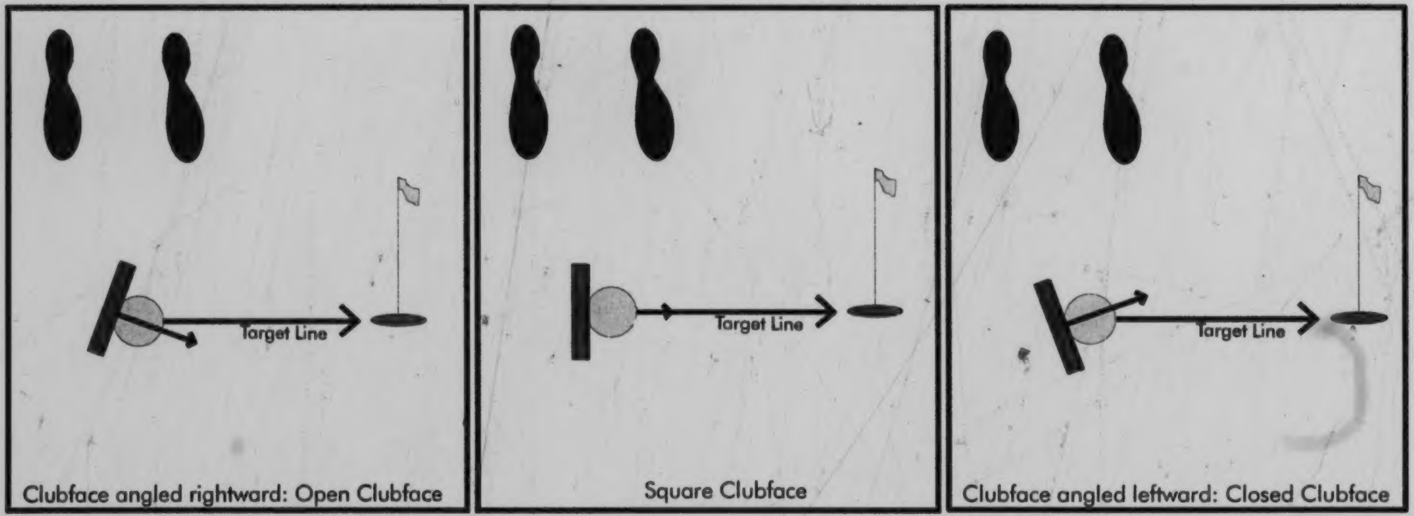
Centre of Clubface

Toe of Clubface

Figure 1. Variations in impact point (IP). The ball may be contacted on the centre of the clubface, or contact may occur forward, toward the toe, or aft, toward the heel of the clubface (Figure was constructed with reference to the following sources: Dawkins, 1976; & Whitecap, 1995).

are often a result of the clubface not meeting the ball squarely. Better golfers have the ability to keep the clubface within three or four degrees of square; while professional tour players can control the clubface within one or two degrees of square (GolfTek, 1998). If the clubface angle is other than "square" or 90 degrees to the direction of travel, a spin will be imparted to the golf ball. Leftward angling of the clubface induces a counter clockwise spin on the ball which causes a flight path that curves to the left of the target. In contrast, rightward angling of the clubface produces a flight path that curves to the right of the target as a result of a clockwise spin imparted to the ball (Dawkins, 1976). Open, closed, and square clubface variations are illustrated in Figure 2.

Clubhead Swing Path (SP). The clubhead can either move straight toward the target, or toward the left or right of the target. Therefore, the path that the clubhead takes during the golf swing refers to the horizontal direction or movement of the club as the ball is contacted. During a correct swing, the clubhead travels *directly* along the ball-to-target line at impact. The optimal clubhead path may also be inside-out, as long as it is not much more than four degrees off a straight path (GolfTek, 1998). An exaggerated inside-out path (e.g., eight degrees), produces a shot that curves to the left of the target; whereas, a consistently exaggerated outside-in swing path commonly leads to a golf shot that curves to the right of the target. Variations in clubhead swing path are illustrated in Figure 3.



Clubface angled rightward: Open Clubface

Square Clubface

Clubface angled leftward: Closed Clubface

Figure 2. Variations in clubface angle (CA). The clubface may either be facing square to the target line or angled to the right (open clubface) or left (closed clubface) of the target line (Figure was constructed with reference to the following sources: Dawkins, 1976; & Whitecap, 1995).

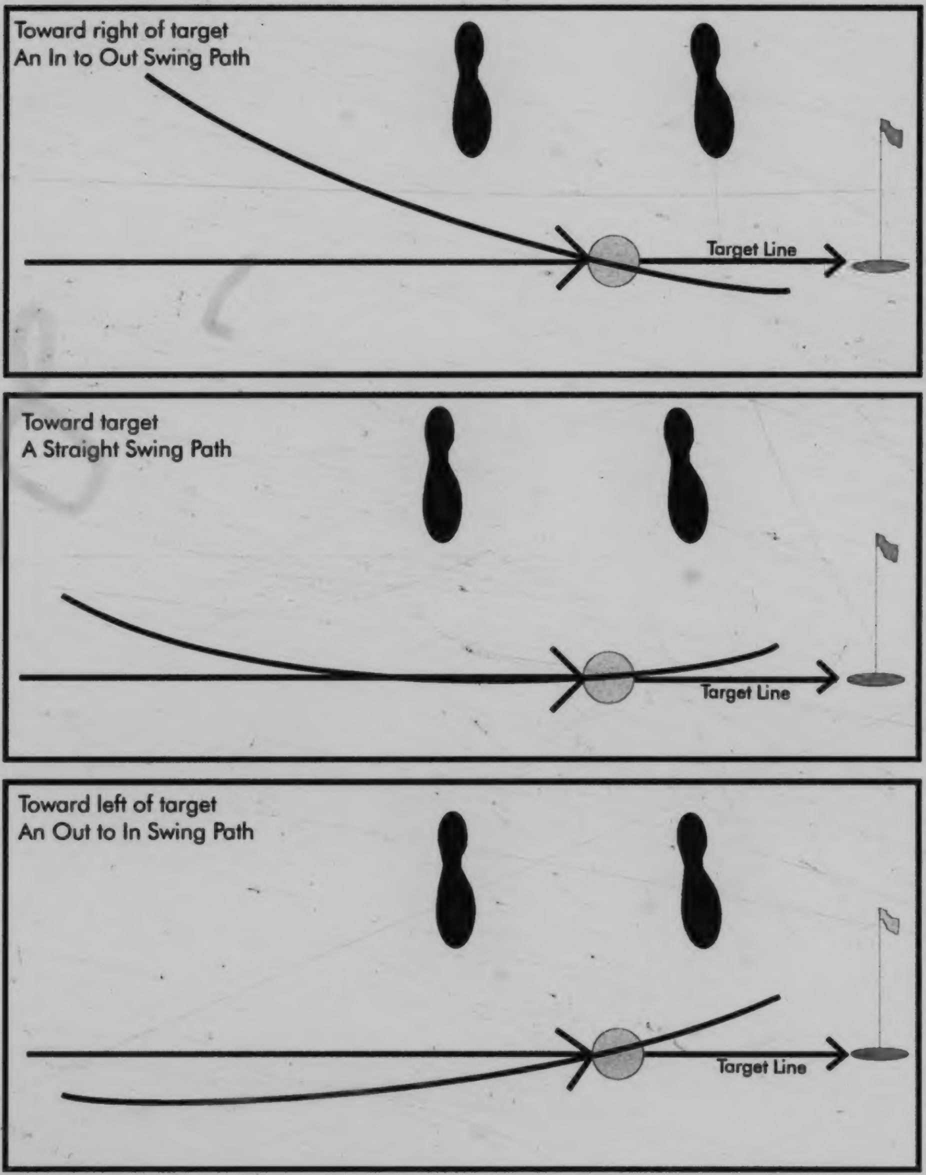

Toward right of target
An In to Out Swing Path
Target Line
Toward target
A Straight Swing Path
Target Line
Toward left of target
An Out to In Swing Path
Target Line

Figure 3. Variations in clubhead swing path (SP). The clubhead can either move straight toward the target, or along an inside-out or outside-in swing path (Figure was constructed with reference to the following sources: Dawkins, 1976; Whitecap, 1995).

The Relationship between Clubface Aspects and Flight Characteristics.

Combinations of clubface angle and swing path produce different flight paths which can be categorized into nine types of ball flight. The nine possible flight paths are demonstrated in Figure 4. Although some of the shots are more desirable than others, the clubface angle and clubhead swing path interact to dictate the direction of every shot. To develop a better understanding of this interaction the slice and hook are discussed. The presentation assumes a right-handed golfer.

The Slice. One of the most common and frustrating problems for the beginning and average golfer, is the slice. A slice is a shot where the ball starts left of the swing path before curving violently to the right. Such a shot typically occurs when the clubhead comes from outside to inside the target line and the clubface is open at impact. This imparts a clockwise spin to the ball (GolfTek, 1998; Haber, 1974; Whitecap, 1995) and is illustrated in Figure 5.

The Hook. A hook is a shot where the ball starts right of the swing path before curving violently to the left. A hook is a common fault of advanced golfers and occurs when the clubhead passes along an in-to-out path with the clubface closed at impact. A hook, therefore, is characterised by a counter clockwise spin to the ball (GolfTek, 1998; Haber, 1974; Whitecap, 1995) and is illustrated in Figure 6.

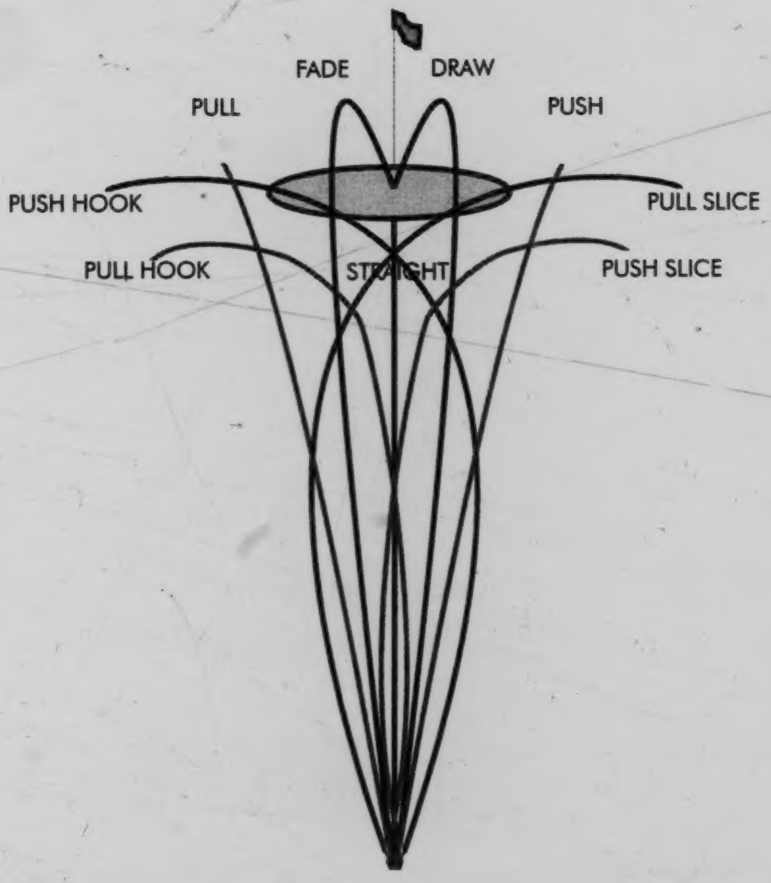

FADE
DRAW
PULL
PUSH
PUSH HOOK
PULL SLICE
PULL HOOK
STRAIGHT
PUSH SLICE

Figure 4. Illustration of the nine possible flight paths of the golf ball. clubhead swing path (SP) and clubface angle (CA) interact to dictate the direction of every shot (Figure was constructed with reference to the following source: Whitecap, 1995).

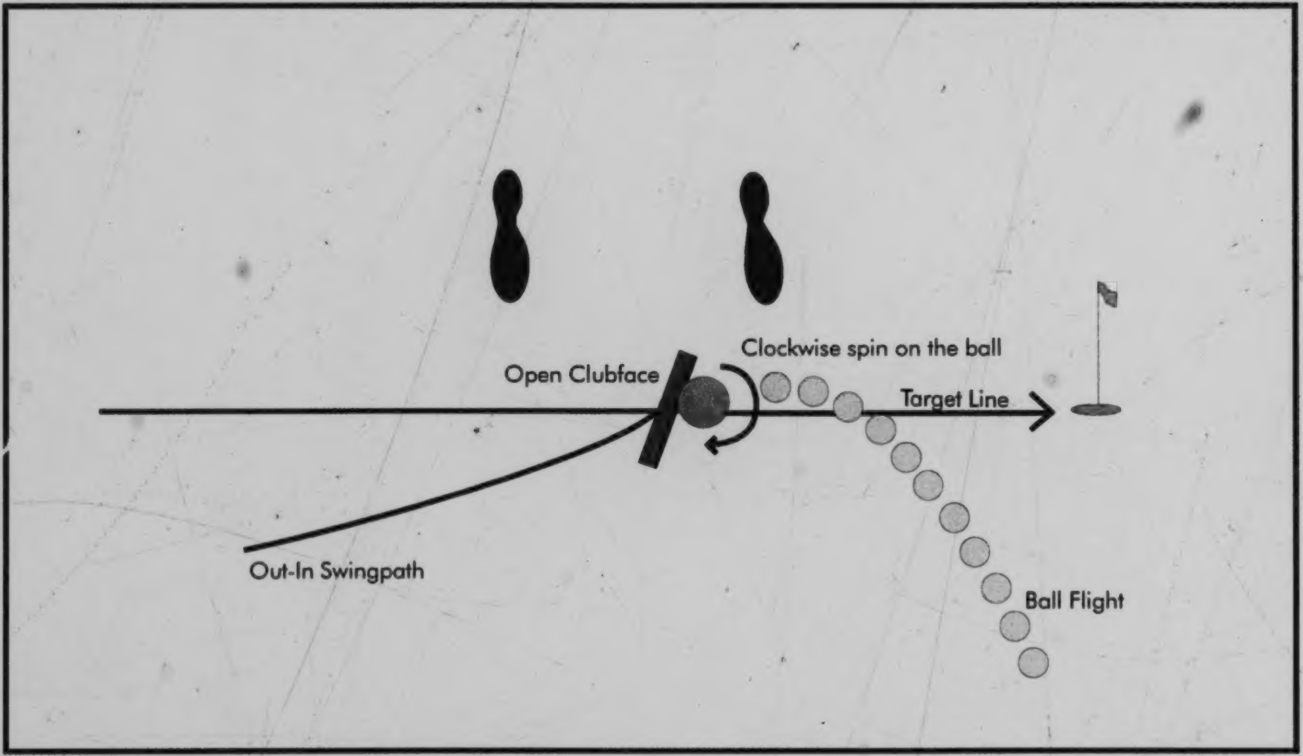

Clockwise spin on the ball
Open Clubface
Target Line
Out-In Swingpath
Ball Flight

Figure 5. Diagram depicting a slice shot. The clubhead comes from outside to inside the line, with an open clubface at impact. The ball starts left of the target before curving sharply to the right (Figure was constructed with reference to the following sources: Dawkins, 1976; Haber, 1974).

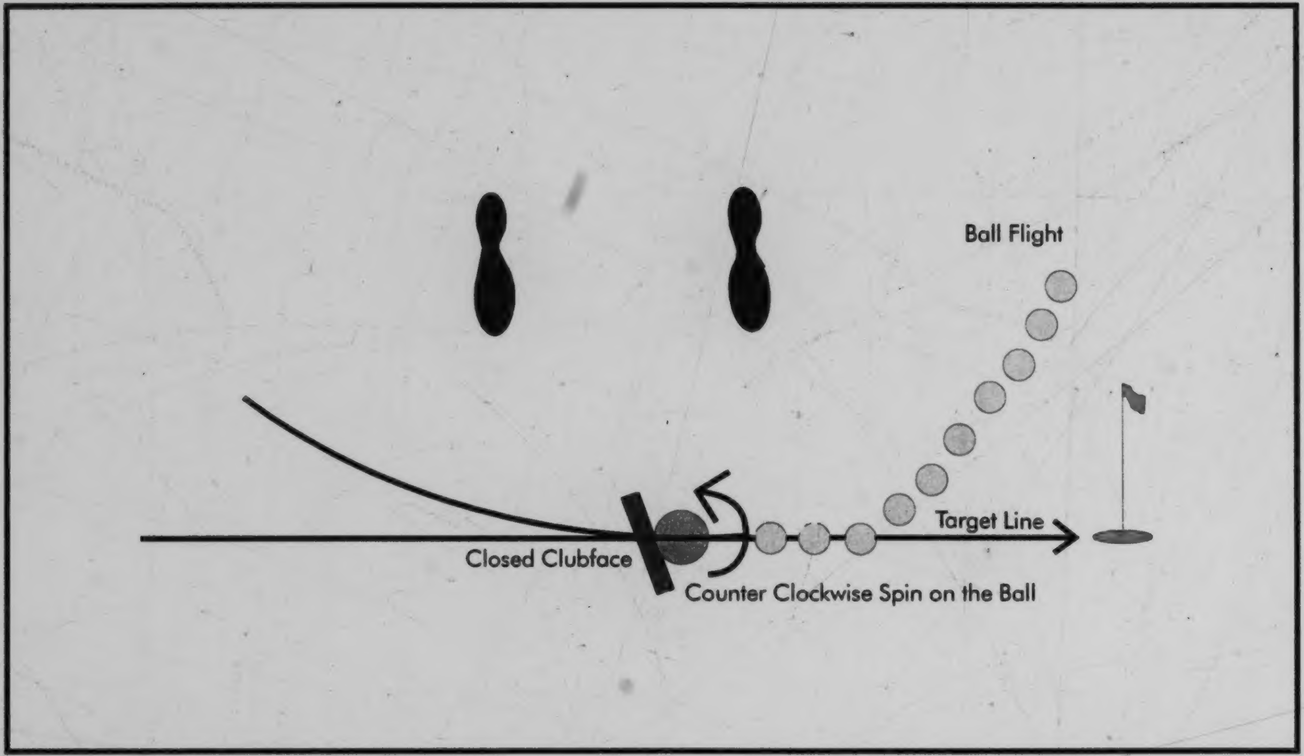

Ball Flight
Target Line
Closed Clubface
Counter Clockwise Spin on the Ball

Figure 6. Diagram depicting a hook shot. The clubhead comes from inside to outside the line, with a closed clubface at impact. The ball starts straight (or slightly right) and curves violently to the left (Figure was constructed with reference to the following sources: Dawkins, 1976; Haber, 1974).

Measuring Clubface Aspects

In the past, individuals investigating motor expertise have experienced difficulty *accurately* and *objectively* quantifying natural human movement. For example, when evaluating success in a closed motor skill (e.g., dance), observers or judges are commonly used to quantify the proficiency of a movement. Unfortunately, whenever measurement procedures call for another person to observe or rate one movement as being superior to another, there is a danger that "prior experience, political views, or personal opinions" (Carnahan, 1993, p. 36), will interfere with judgements regarding the movement form (Ste-Marie & Lee, 1991). Therefore, when the technology is available, it is advantageous to use these instruments to increase accuracy and objectivity when attempting to quantify movement. Recently, an instrument referred to as the GolfTek Pro V Swing Analyzer™, has been developed to measure such movement attributes as clubface angle, travel path, and impact point, during the execution of a golf swing. Initially designed for swing analyses, clubfitting, and teaching purposes (GolfTek, 1998), this piece of technology can also be used in a research setting to objectively measure clubhead aspects in a direct, but unconstrained manner.

CHAPTER IV

TESTING THE VALIDITY AND RELIABILITY OF THE GOLFTEK PRO V SWING ANALYZER™ : STUDY ONE

Introduction

An acceptable instrumentation system must possess both accuracy and precision. Accuracy essentially refers to the system's validity and is defined as the closeness with which the instrument reading approaches the true value (Hubbard, 1974) or measures what it purports to measure (Smith & Glass, 1987). Since instrumentation systems give only an approximation of the value being measured, it is necessary to know the degree of error inherent in the instrument under normal operating conditions (Hubbard, 1974). In addition, it is also essential to ascertain the degree to which the instrument yields the same score on repeated or identical inputs. This is referred to as measurement precision and is used to indicate the reliability or dependability of the instrumentation system. If, for example, the instrument yields widely discrepant scores among repeated readings, the discrepancy is thought of as instrument error. As such, the more variability that exists among scores, the greater the existing amount of error, and correspondingly, the lower the instrument reliability (Smith & Glass, 1987). However, if the same value of the measured variable is measured many times and the results agree very closely, the instrument is thought to possess a high degree of precision or reproducibility (Hubbard, 1974). In light of this discussion, one must ask the following two questions regarding the GolfTek Pro V Swing Analyzer™: (1) Does the Pro V System yield scores that serve the function for which it was intended?; and, (2) Does the Pro V System consistently reproduce the same score on identical inputs? Although the Pro V Instruction manual (GolfTek, 1998) states, "all data displayed by the analyzer are direct measurements and are *very accurate*" (p. 15), the company fails to publicly support this statement with empirical evidence. Thus, before the Pro V System could be used as a research instrument in this project, both validity and reliability tests were required to establish the accuracy (validity) and precision (reliability) of the instrumentation system.

This chapter begins with a description of the GolfTek Pro V Swing Analyser™, followed by a section describing how CA, IP, and SP measurements were procured by the system. This chapter also includes an outline of the method and procedures utilised in the evaluation of instrument accuracy and reliability, as well as the results of the validation/reliability assessment. Implications for using the GolfTek Pro V System in a research setting are also presented.

The GolfTek Pro V Swing Analyzer™

The Pro V system obtains clubface measurements using sensors which function by way of a light source positioned directly over the tee area. The sensors are located in the base of the system and are protected by a soft poron shock mat which is covered by a piece of clear lexan plastic and a hard hitting mat. The hitting mat is painted green to represent a grass hitting surface (GolfTek, 1998). When the light source is turned on and the club is swung over the mat, a shadow of the club is cast upon the hitting surface. Any sensor that the shadow touches, responds by switching off until the shadow passes over the triggered sensor and the disturbance in light source is no longer present. This sensor information is then fed from the Pro V through an attached data cable into a computer.

GolfTek software prepares the clubface measurements which are accessible to the system operator using the GolfTek PF-123 Graphics Program™. It should be noted that each sensor is designed to procure a particular parameter aspect, some of which were not used in this project (e.g., swing tempo, clubhead speed). Therefore, measurements for each clubface aspect (CA, IP, and SP), were determined according to which sensors were triggered on route to ball contact. The purpose of the following section is to identify the sensors used to obtain CA, IP, and SP, by describing the manner in which the clubhead shadow and sensors function to produce these particular swing parameters.

Clubface Angle (CA)

Clubface angle was defined by the Pro V System as the angle of the clubface at the moment of impact with respect to the target line. Therefore, measurements regarding clubface angle (CA) were secured as soon as the shadow of the club touched a sensor in rows three and four (identified as sensors 27-34, and 35-42) (refer to Figure 7), positioned (32 mm) behind the tee. If the club shadow, for example, touched the two groups of sensors identified as 27-34 and 35-42 simultaneously, the clubface angle was reported to be *square* at ball contact. For a right-handed player, if the club shadow touched a sensor identified in row four (35-42) before a sensor in row three (27-34), the clubface angle was expressed as a *closed* angle. In contrast, an *open* angle was denoted if the club shadow touched a sensor in row three (27-34) before a sensor in row four (35-42). The relationship between clubface shadow and sensors 27- 42 for clubface angle is illustrated in Figure 8.

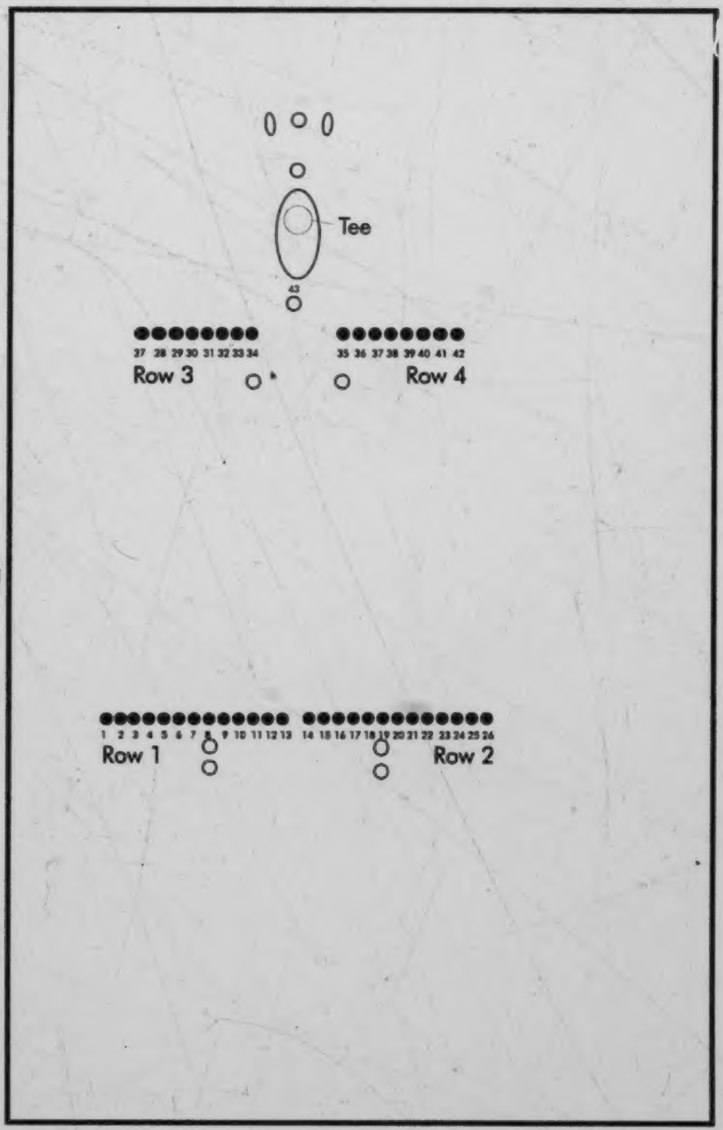
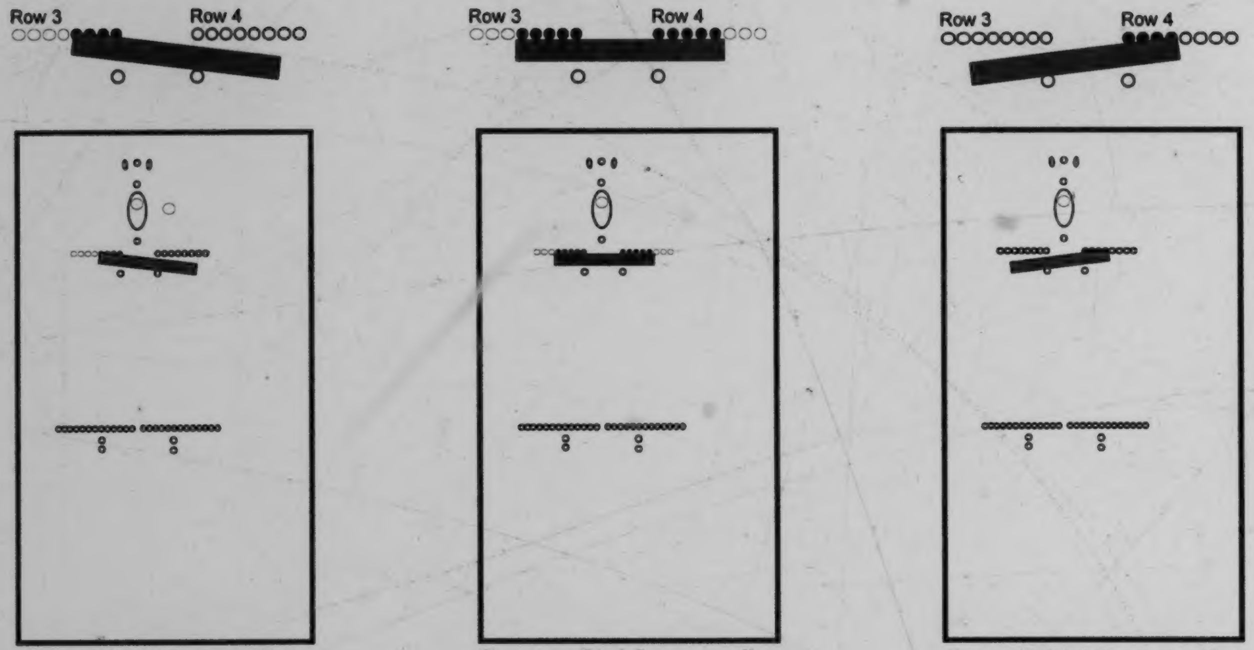

Tee
43
27 28 29 30 31 32 33 34
Row 3
35 36 37 38 39 40 41 42
Row 4
1 2 3 4 5 6 7 8 9 10 11 12 13
Row 1
14 15 16 17 18 19 20 21 22 23 24 25 26
Row 2

Figure 7. Illustration depicting hitting surface of the Pro V mat. Solid circles represent sensors used to calculate clubface angle (CA), impact point (IP), and clubhead swing path (SP), and are referred to by sensor and row number within the text.



Open Clubface reading

Square Clubface reading

Closed Clubface reading

Figure 8. Sample illustration of relationship between clubface shadow and sensor rows three and four for clubface angle (CA). Note: Illustration depicts the shadow-sensor relationship for a right-handed player.

Impact Point **(IP)**

The point of clubface-ball contact was captured by the system when the shadow of the clubface crossed sensor rows 27-34 and 35-42 (refer to Figure 7 for sensor identification). It was speculated[1] that this sensor data was used in conjunction with specific clubhead information to calculate "how far off centre the ball was struck" (GolfTek, 1998, p. 9). Clubhead information refers to the type of club (e.g., driver) and the size of the clubhead (standard, mid-size, or jumbo) that the operator selects in the GolfTek program prior to system use. Therefore, the GolfTek system takes clubhead differences into account for an accurate calculation of clubface impact point.

Clubhead Swing Path **(SP)**

The swing path, acknowledged by the system as the horizontal approach angle of the club moving into the impact zone, was defined as "the area six inches prior to impact up to the moment of impact" (GolfTek, 1998, p. 9). Thus, measurements for swing path were calculated in relation to target line and acquired using information obtained when the clubface shadow crossed sensors in rows one and two and sensors in rows three and four (identified as sensors 1-13, 14-26; and 27-34, 35-42, respectively) (refer to Figure 7 for sensor identification). For a right-handed player, if the clubface shadow first touched a sensor in row two (14-26), the clubhead path was expressed to be travelling on an outside to in path in comparison to the target line. However, if the clubface shadow first touched a sensor in row one (1-13), the clubhead path was expressed to be travelling on an inside to out path in comparison to the target line. The relationship between clubface shadow and the Pro V sensors is illustrated in Figure 9.

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[1] The term speculated is used when discussing computational aspects of the Pro V system. Unfortunately, the author received limited cooperation from GolfTek Inc. regarding the operation, and accuracy and precision of the Pro V system. After a substantial amount of testing to discern sensor operation, verbal confirmation was received from GolfTek that the author had correctly identified the sensors that were involved in the parameter measurements of CA, IP, and SP.

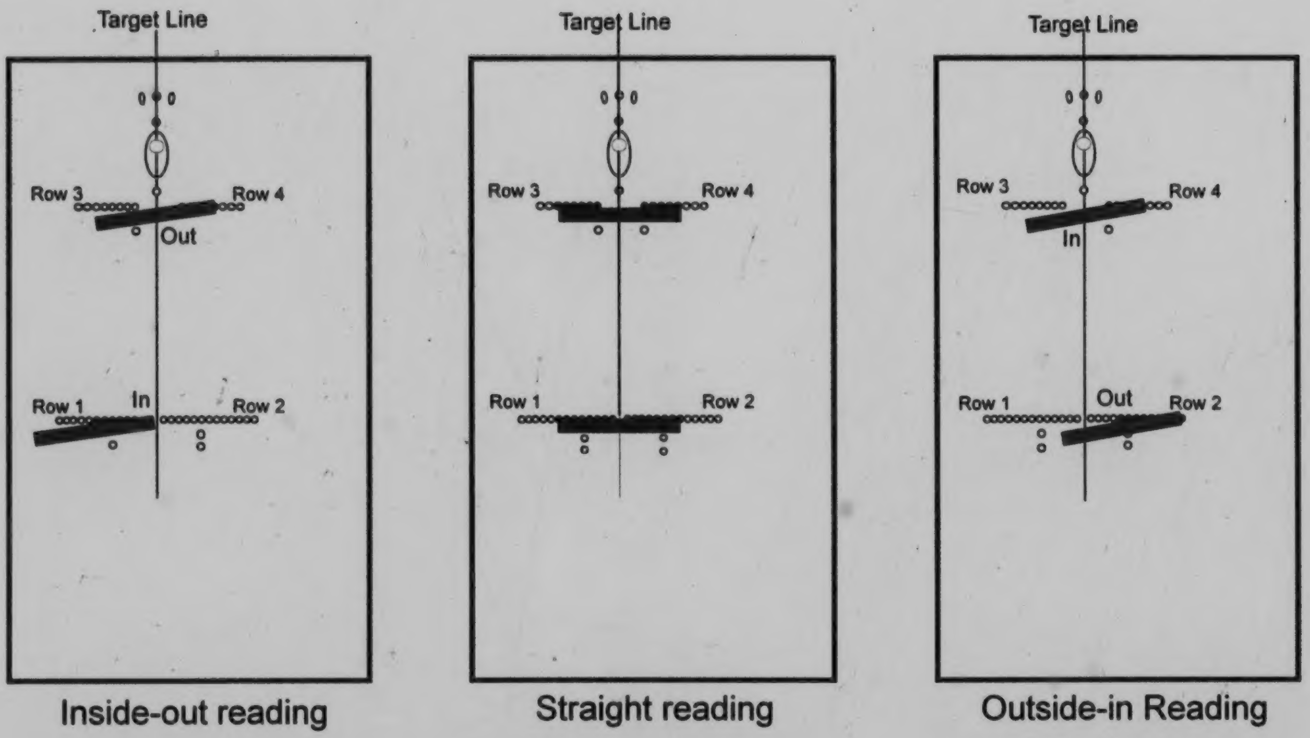
Target Line
Row 3
Row 4
Out
Row 1
In
Row 2
Inside-out reading
Target Line
Row 3
Row 4
Row 1
Row 2
Straight reading
Target Line
Row 3
Row 4
In
Row 1
Out
Row 2
Outside-in Reading

Figure 9. Sample illustration of relationship between clubface shadow and sensor rows one to four for clubhead swing path (SP). Note: Illustration depicts shadow-sensor relationship for a right-handed player.

Method

Apparatus and Validation Approach

To validate the accuracy of the Pro V system, each parameter (CA, IP, and SP) was controlled for and tested separately. In order to examine the Pro V system over a complete range of use and in a controlled condition for each parameter, an apparatus was constructed to allow a golf club to be repeatedly swung over the Pro V mat at the particular clubface angle or position being tested for. Essentially, the constructed apparatus functioned as a golf pendulum and is illustrated in Figure 10. When considering a golf swing is commonly related to the motion of a pendulum, utilising such as apparatus proves an ideal method for testing the validity and reliability of the Pro V system.

In an attempt to examine the Pro V system over a complete range of use, the pendulum was set-up to assess either seven or nine pre-determined measurements for each clubface aspect. Validity for clubface angle was analysed using the following seven angles: closed nine (- 9°), six (-6°), and three (-3°) degrees; square (0°); and open three (3°), six (6°), and nine (9°) degrees. Impact point was evaluated on the heel 0.25 inches, 0.50 inches, and 0.75 inches; on the centre (referred to as 0 inches); and on the toe 0.25 inches, 0.50 inches, and 0.75 inches. Finally, swing path was assessed using nine clubhead paths: outside-in two (-2°), four (-4°), six (-6°), and eight (-8°) degrees; straight; and inside-out two (2°), four (4°), six (6°), and eight (8°) degrees. If the Pro V system yielded the appropriate measurement on each trial when the pendulum was positioned and set-up to elicit that particular measurement, the system would be

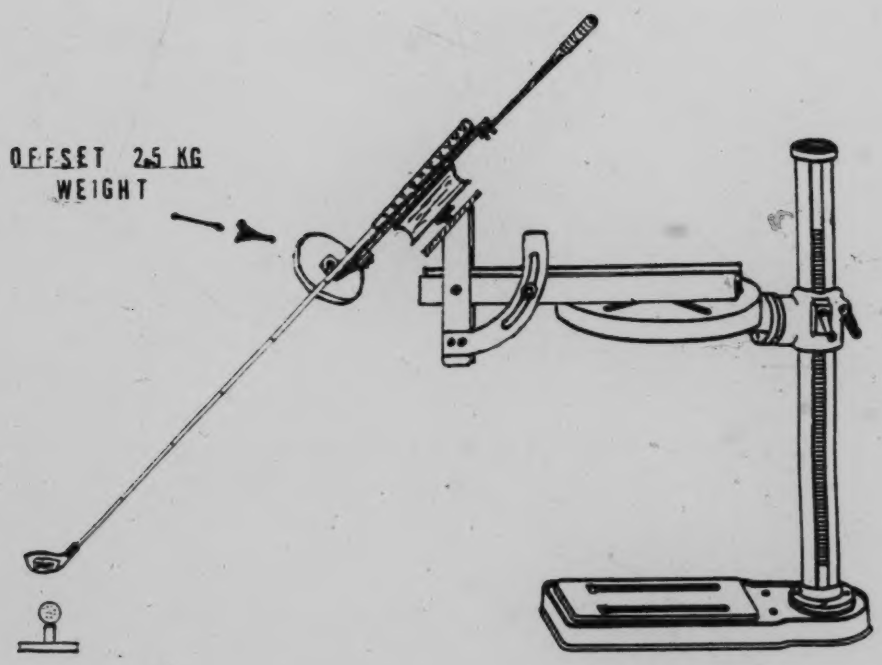
OFFSET 2.5 KG
WEIGHT

Figure 10. Illustration of validity and reliability assessment apparatus: The golf pendulum.

considered a valid instrument with which clubface aspects could be procured. Furthermore, since the same value will be measured many times (n = 25 trials/measurement), a reliability assessment will also be obtained for the parameter being controlled for, as well as for the two clubface aspects not currently exposed to the validation assessment. If the results agree very closely on repeated trials, the instrument will be considered to possess a high degree of precision or reliability.

Positioning the Pendulum

In an attempt to elicit each measurement for all three clubface aspects (CA, IP, and SP), the pendulum was set-up so that the shadow of the clubhead would trigger particular sensors in the appropriate manner. The purpose of the following section is to illustrate the procedure used to set-up the pendulum so that the appropriate angle, impact point, and swing path were properly controlled for.

Clubface Angle (CA). To position the pendulum, a clear overhead projection sheet was secured on the hitting surface of the Pro V mat. Depending on whether an open or closed angle was to be elicited, the origin of a clear protractor was placed in the middle of sensor 34 or 35, respectively, and the base of the protractor was lined up directly with the bottom of the two sensor rows. The desired angle (e.g., open 9°, closed 9°), was marked on the overhead sheet. The shaft of the club was then manipulated to elicit a shadow in the impact zone at the desired angle. To elicit a square reading, the club shaft was manipulated until the clubface rendered a shadow parallel to the two sensor rows. Once the appropriate angle was achieved, the screws securing the shaft of the club to the pendulum were tightened and the shadow angle was re-checked with the protractor to ensure that the shaft had not moved with the tightening of the screws. An example of the golf pendulum positioning procedure for clubface angle (CA) is displayed in Figure 11.

Impact Point (IP). Before positioning the golf pendulum over the Pro V sensors, the seven clubface impact points (0.25", 0.50", 0.75" towards the heel/ toe; and centre) were measured and marked on the face of the club. For each trial set, the pendulum was positioned so that the desired impact point swung directly over the middle space between sensor rows three (27-34) and four (35-42), sensor 43, and the middle of the rubber tee (Figure 7). Impact point adjustments were made by moving the pendulum towards the hitting mat or away from the mat. Such movement accounted for alterations towards the heel or towards the toe of the club, respectively. No adjustments were made to the shaft of the club (manipulation of clubface angle), nor was the pendulum rotated clockwise or counterclockwise (manipulation of clubhead swing path) when positioning the pendulum for impact point.

Clubhead Swing Path (SP). To position the pendulum, a clear overhead projection sheet was secured on the hitting surface of the Pro V mat. On the projection sheet, a straight line was drawn on top and parallel to sensors 27-42, and the middle of the space between the two sensor rows was marked. This procedure was repeated on the top of sensors 1-26, and the middle of the space between these two sensor rows was also marked. A straight line perpendicular to both sensor rows was then drawn connecting the two middle marks, and was identified as the target line. The origin of a protractor was placed on the middle mark between sensor rows three (27-34) and four (35-42), and positioned at a 90° angle to either sensor row one or two depending on the desired path

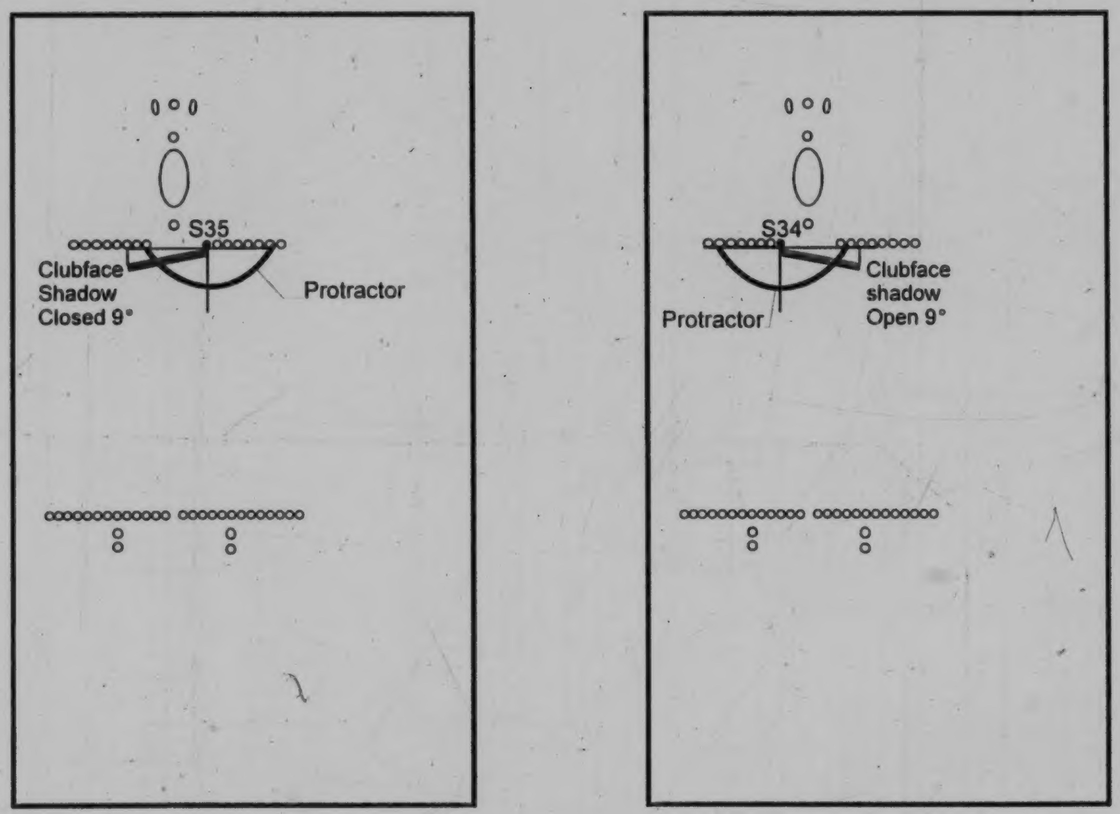
S35
Clubface Shadow Closed 9°
Protractor
S34°
Protractor
Clubface shadow Open 9°

Figure 11. Example of golf pendulum positioning procedure for clubface angle (CA) validity assessment. Note: Diagram depicts pendulum set-up for a right-handed club.

angle. The base of the protractor was lined up directly on the target line and the desired angle (e.g., Inside-out 6°, Outside-in 6°) was then marked on the overhead sheet at sensor row one or two. To achieve the swing path angle, the base of the pendulum was rotated clockwise (an inside-to-out swing path) or counterclockwise (an outside-to-in swing path) until the centre of the clubface was positioned directly over the marked angle. No adjustments were made to the shaft of the club (manipulation of clubface angle) when positioning the pendulum for swing path. This positioning procedure is illustrated in Figure 12.

Testing Procedure

Before testing each measurement for CA, IP, and SP, a plum line was dropped from the light source to ensure the tee of the golf mat was situated directly below the source of light. The pendulum was then positioned at the appropriate angle (CA or SP) or position (IP) by the previously described procedures. Using the pendulum handle, the club was brought up to a marked height of two feet, and was then allowed to swing freely over top the Pro V system. The club was stopped by the experimenter on the upswing of the follow-through at a height of approximately two feet. This procedure was repeated twenty-five times for all control measures of each parameter (23 control measures x 25 swings/control measure = 575 trials).

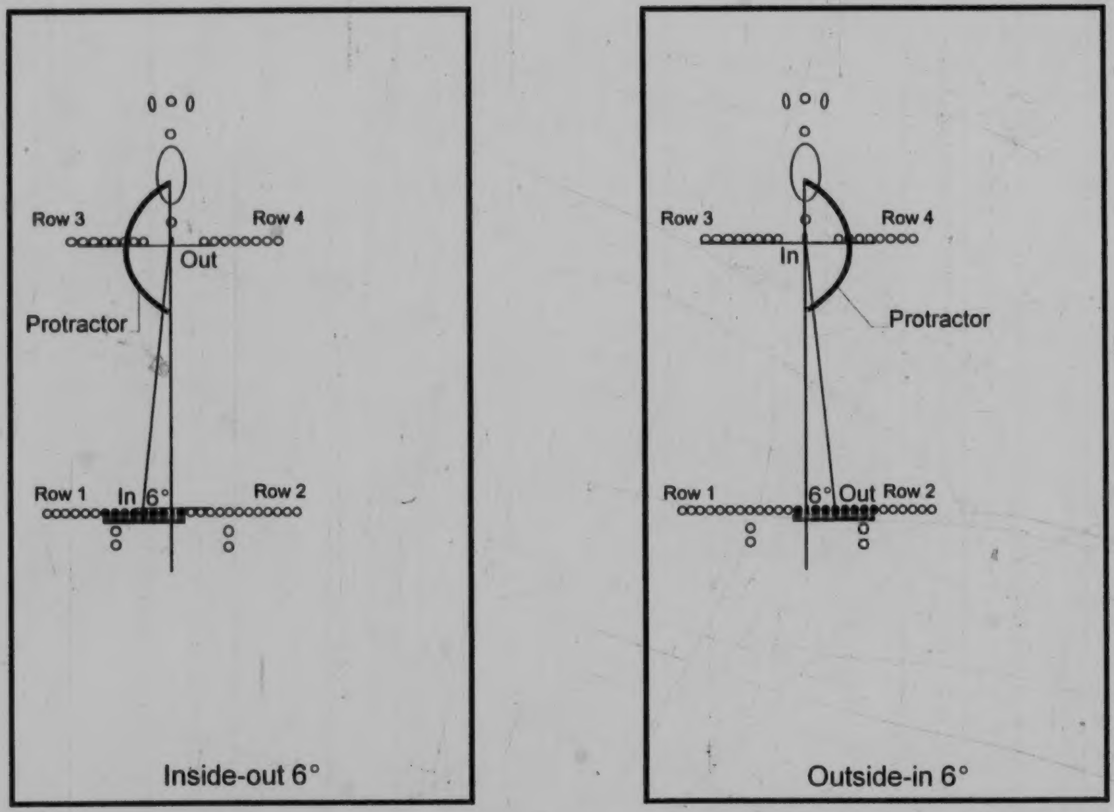
Row 3
Row 4
Out
Protractor
Row 1
In
6°
Row 2
Inside-out 6°
Row 3
Row 4
In
Protractor
Row 1
6°
Out
Row 2
Outside-in 6°

Figure 12. Example of golf pendulum positioning procedure for clubhead swing path (SP) validity assessment. Note : Diagram depicts pendulum set-up for a right-handed club.

Results

Analysis of the validation scores revealed that there was no systematic error with regards to: CA over a range of ± 9° (Table 1), IP over a range of ± 0.75 inches (Table 2), and SP over a range of ± 8° (Table 3). Analysis of CA reliability scores revealed score outputs within one degree of each other for all sets of 25 trials, when controlling for IP and SP (Tables 2 and 3). Impact point reliability scores were identical over all trials, when controlling for CA and SP (Tables 1 and 3). Furthermore, swing path reliability scores were also identical over all trials, when controlling for CA and IP (Tables 1 and 2).

Although the primary focus of this study was to assess the validity and reliability of the Pro V system when a hitting a golf ball off the system with a wood, two additional instrument qualities were observed and merit a word of mention. The first observation pertains to instrument sensitivity; whereas, the second deals with the notion of rangeability.

The Pro V system appears to be an effective instrumentation tool for the research setting since it was found to be quite sensitive to minute changes in clubface parameters. When manipulating clubface angle, the system responded to one degree changes in the shadow angle of the clubface. Accordingly, the system displayed greatest sensitivity to this parameter and reported measurements for CA in increments of one degree (e.g., -2° → -1° → 0° → 1° → 2°). The least sensitive reaction was impact point where the system reacted to quarter inch changes in impact point and reported IP in 0.25 inch increments (e.g., -0.50"→ -0.25" → 0 → 0.25" → 0.50"). Finally, the system recognized two degree changes in swing path angle and reported this parameter in increments of two degrees

Table 1

GolfTek Pro V Validity and Reliability Assessment Scores Controlling for Clubface Angle (CA)

Primary Parameter			Secondary Parameter			
Clubface Angle (degrees)	Clubface Angle (degrees)		Impact Point (inches)		Swing Path (degrees)	
Pendulum	Mean	SD	Mean	SD	Mean	SD
-9.0	-9.0	0.0	0.0	0.0	-2.0	0.0
-6.0	-6.2	0.4	0.0	0.0	-2.0	0.0
-3.0	-2.9	0.3	0.0	0.0	-2.0	0.0
0.0	0.0	0.2	0.0	0.0	-2.0	0.0
3.0	3.0	0.0	0.0	0.0	-4.0	0.0
6.0	6.0	0.0	0.0	0.0	-2.0	0.0
9.0	8.2	0.4	0.0	0.0	-2.0	0.0

Table 2

GolfTek Pro V Validity and Reliability Assessment Scores Controlling for Impact Point (IP)

Primary Parameter			Secondary Parameter			
Impact point (inches)	Impact point (inches)		Clubface Angle (degrees)		Swing Path (degrees)	
Pendulum	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
-0.75	-0.75	0.00	-5.0	0.0	2.0	0.0
-0.50	-0.50	0.00	-7.0	0.0	0.0	0.0
-0.25	-0.25	0.00	-4.5	0.5	0.0	0.0
0.00	0.00	0.00	-2.0	0.0	0.0	0.0
0.25	0.25	0.00	-10.0	0.2	0.0	0.0
0.50	0.50	0.00	-5.0	0.0	0.0	0.0
0.75	0.75	0.00	0.4	0.5	0.0	0.0

Table 3

GolfTek Pro V Validity and Reliability Assessment Scores Controlling for Swing Path (SP)

Primary Parameter			Secondary Parameter			
Swing Path (degrees)	Swing Path (degrees)		Clubface Angle (degrees)		Impact Point (degrees)	
Pendulum	Mean	SD	Mean	SD	Mean	SD
-8.0	-8.0	0.0	5.7	0.5	0.0	0.0
-6.0	-6.0	0.0	3.0	0.0	0.0	0.0
-4.0	-4.0	0.0	1.0	0.0	0.0	0.0
-2.0	-2.0	0.0	-1.0	0.0	0.0	0.0
0.0	0.0	0.0	-2.0	0.0	0.0	0.0
2.0	2.0	0.0	-4.4	0.5	0.0	0.0
4.0	4.0	0.0	-6.0	0.0	0.0	0.0
6.0	6.0	0.0	-7.4	0.5	0.0	0.0
8.0	8.0	0.0	-0.1	0.3	0.0	0.0

(e.g., -4° → -2° → 0° → 2° → 4°).

To facilitate precision, it was found that the system also displayed a large range of output scores with accuracy. For clubface angle, scores extended on the continuum from closed 16 degrees to open 16 degrees (-16°→ 0° →16°). The largest values registered with accuracy on the continuum for impact point was 0.75 inches on the heel and 0.75 inches on the toe (-0.75"→ 0" → 0.75") (see chapter note for further validation details regarding IP boundaries). Finally, the swing path parameter also exhibited a large range registering values with accuracy from outside-in 14 degrees to inside-out 14 degrees (-14°→ 0° →14°).

Concluding Statement

Review of the findings suggests that the Pro V system yields acceptable levels of accuracy and precision for all clubface aspects (CA, IP, and SP). Furthermore, the system displayed a sensitivity to small parameter changes, and exhibits a potential for capturing a variety of swing attributes since it can report a large range of measurements for each parameter. These findings provide empirical evidence supporting the use of the GolfTek Pro V Swing Analyser™ to procure CA, IP, and SP measurements when the golf ball is hit off the tee with a wood (i.e., driver) (see chapter note for further details regarding choice of club).

Chapter Note

Since participants were asked to a hit a large number of balls, it should be noted that the initial project design called for the use of a five-iron rather than the driver or three wood. A five-iron is a much lighter club than both a driver or three wood, and therefore, should not fatigue a golfer to the same extent. However, after setting up the pendulum and measuring the CA variable for validity, the measurements were found to be quite inconsistent and in fact, invalid on more than one occasion. Consequently, the Pro V system was inspected under greater scrutiny in an attempt to reveal the source of the invalid and unreliable readings. First, the pendulum was checked to see if it was possible for the club shaft to be moving or twisting after being released in the air. Upon inspection this possibility was ruled out as the source of error since it was quite difficult to move the club shaft even a degree without a tremendous amount of force exerted on the club shaft. Further examination revealed two design flaws as the source of the invalid CA measurements.

The first design flaw pertains to the 32 mm space between sensor rows three (27-34) and four (35- 42) on the Pro V mat (refer to Figure 7). When the clubface was set up greater than 0.75 inches on the toe (e.g., one inch) with a closed face, it was observed that the shadow segment of the clubhead toe fell over the sensor-free portion of the mat. This design flaw has severe consequences with regards to the actual clubface angle registered by the system. Although the clubface was clearly set up to elicit a closed reading, the segment of the clubhead shadow first to trigger the sensors was the heel of the iron rather than the shadow segment of the toe. Consequently, this yielded an invalid open clubface reading. Consequences of this design flaw are illustrated in Figure 13.

The second flaw pertains to the way in which a five iron is designed. All irons are fashioned so that the hosel protrudes ahead of the blade. Accordingly, the hosel of the club will trigger the sensors before the actual clubface which, elicits an open face on the system, even when the iron is clearly set up to yield a closed face measurement.

This finding reveals that inappropriate CA readings occur when using an iron, or hitting the club largely on the toe. Under these circumstances, the Pro V system is clearly an invalid method with which to measure clubface angle. Therefore, a repercussion of these findings for the project method was that any trial exhibiting a measurement of one inch or greater on the toe of a standard wood (≥1.25" on the toe of a mid-sized, wood, and ≥1.5" on the toe of an over-sized wood), must be discarded from the data set. Further, participants could not use an iron or an "off-set" driver to hit the required series of golf balls. The term "off-set" refers to the amount by which the leading edge or bottom of the clubface is set behind the plane of the front of the hosel. The more off-set, the more the clubhead trails the shaft as it swings through the ball. Although an off-set driver was not tested on the pendulum, its design would produce readings similar to those obtained on the Pro V system by an iron. By virtue of the above findings, the off-set driver was also deemed an inappropriate club to use if accurate and reliable measurements were to be obtained on the Pro V system.

Considering that the GolfTek Pro V Swing Analyser™ is used as a device to correct swing fundamentals and clubfitting, the implications of these findings are not only a concern for this study, but for the application of this instrumentation device whenever

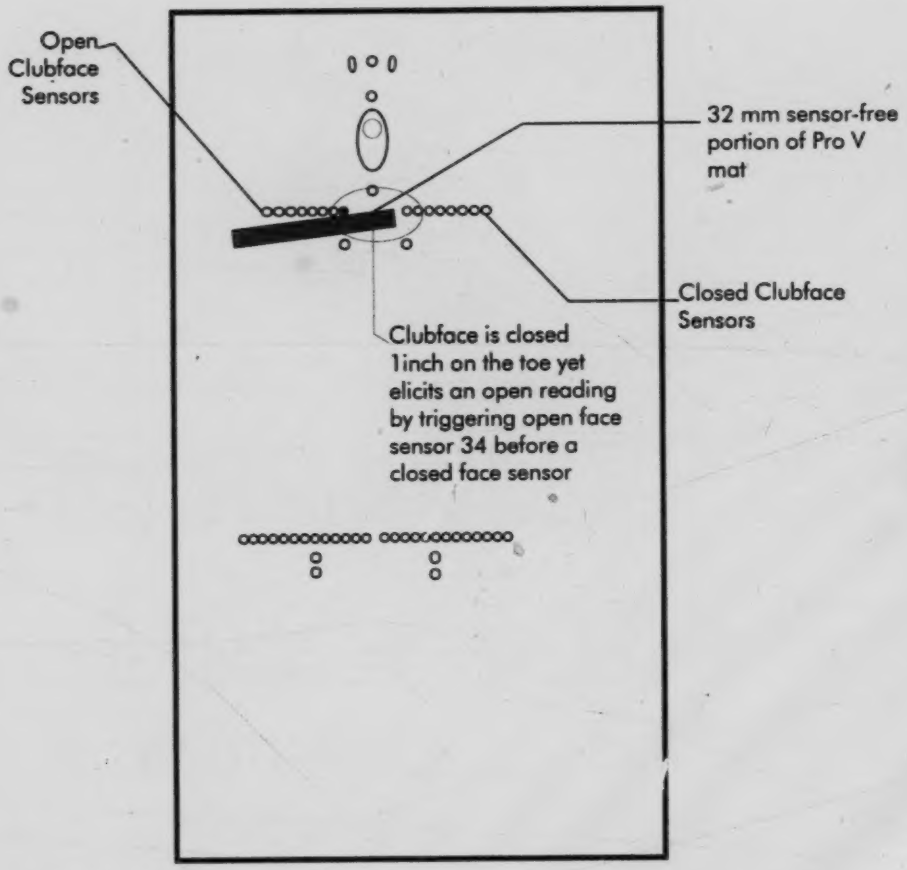
Open Clubface Sensors
32 mm sensor-free portion of Pro V mat
Closed Clubface Sensors
Clubface is closed 1inch on the toe yet elicits an open reading by triggering open face sensor 34 before a closed face sensor

Figure 13. Diagram illustrating consequences of design flaw in the GolfTek Pro V mat. When the ball is struck greater than 0.75" on the toe of a standard club, the shadow of the toe falls over the sensor-free portion of the mat. Although the clubface is closed, the system reports an open clubface reading.

an iron or an off-set driver is used for the aforementioned purposes.

CHAPTER FIVE

STUDY TWO

Purpose

This study was designed to address whether performers in the latter stages of skill acquisition display superior judgements of movement production accuracy (error detection) than novice performers regarding the execution of a complex motor skill.

Method

Participants

Twenty male golfers possessing a handicap of 10 or below, or a handicap between 20 and 30, were recruited from golf clubs throughout a major Canadian city and surrounding community. Individuals with a handicap of 10 or below (n = 10; mean handicap = 6) were referred to as the low (LOW) handicap group, and classified as the more skilled performers in this study. Mean age of the LOW group was 32 years (range = 17 to 51 years). Participants who currently possessed a handicap between 20 and 30 (n = 10; mean handicap = 25) were assigned to the high (HIGH) handicap group and classified as the novice or less skilled participants. Mean age of the HIGH group was 31 years (range = 25 to 45 years). Table 4 presents participant characteristics for this study.

Participant Inclusion/Exclusion. In addition to handicap criteria, several stipulations were set prior to subject recruitment regarding participant inclusion for this study. First, any individual who once possessed a handicap fitting the LOW criteria, but currently fits the HIGH criteria, was not included in the study (Thomas & Lee, 1992, cited in Abernethy et al., 1993). The rationale for such a stipulation is based on the notion

Table 4

Participant Characteristics for Study Two

	Participant	Handicap	Age	Years Played*
Low Handicap Group	1	4	28	15-19
	2	10	33	15-19
	3	6	25	15-19
	4	8	38	20-24
	5	8	42	20-24
	6	7	45	20-24
	7	2	19	10-14
	8	8	17	5-9
	9	2	51	20-24
	10	4	21	10-14
Mean		32	32	-
SD		3	12	-
High Handicap Group	11	25	38	5-9
	12	28	25	5-9
	13	30	27	1-4
	14	20	25	5-9
	15	26	37	5-9
	16	20	26	5-9
	17	20	26	5-9
	18	20	45	1-4
	19	30	30	5-9
	20	30	33	5-9
Mean		25	31	-
SD		5	7	-

* Years of golf experience was a self-reported estimate supplied by the participant and is displayed within an approximate category range: 1-4, 5-9, 10-14, 15-19, and 20-24 years.

that many intervening factors may interact to prevent an individual from presently achieving a low handicap (e.g., age). However, such variables may not affect an individual's knowledge base with the same detrimental effects. Although a golfer, once considered highly skilled, may exhibit a deterioration in motor performance, this does not mean the individual has also lost the knowledge base to detect errors in his performance. In the motor literature, knowledge-base approaches to expertise are built around the assumption that although expert and novices have similar 'hardware' (Starkes & Deakin, 1984), experts differ from novices in terms of "what they know and how they utilise that knowledge" (Abernethy et al., 1993, p. 324).

Second, any golfer who had previous experience with the GolfTek Pro V Swing Analyzer within the last year was also prohibited from participating. Individuals exposed to this system within a close time proximity to study testing will have a greater chance of possessing "test-wiseness" as a result of previous exposure to the system. For example, an individual may receive a print-out of his swing profile on the Pro V System which shows his tendency is to swing 'outside-in six or eight degrees'. Since he is on another Pro V system and considering his swing should remain relatively stable over a short period of time, it is most likely the participant will use this knowledge and report 'outside-in six or eight degrees' as his actual score during the test session, regardless of what he might perceive his swing path to be. Borrowed from educational literature, responding in this nature may be termed test-wiseness, and essentially refers to a "subject's capacity to utilize the characteristics and formats of the test and/or test-taking situation to receive a high score" (Millman, Bishop, & Ebel, 1965, p. 709). Therefore, the probability of correctly responding to items susceptible to test-wiseness will increase for these individuals by virtue of prior system use. As such, golfers exposed to the Pro V system within the last year were excluded from study participation.

Due to the available options within the GolfTek PF-123 Graphics Program™, whether an individual swings left- or right-handed was not a criteria for participant exclusion in this study.

Task and Apparatus

Standing on a 148 x 148 cm golf mat commonly used at driving ranges, participants were asked to hit a series of golf balls off a rubber tee with their driver or three wood into safety netting. The tee was placed through a specially designed opening in the GolfTek Pro V Swing Analyzer™ which records swing attributes when the club is swung over the hitting surface of the Pro V mat. As such, measurements of all three clubface parameters (CA, IP, and SP), were obtained from the Pro V system.

Erroneous Readings. To prevent erroneous readings, several precautionary measures were taken. First, a plum line was dropped from the light source to ensure the tee of the golf mat was positioned directly below the light source. Second, the Pro V hitting surface was cleaned with a vacuum cleaner before the start of each testing session to eradicate the potential of particles and dust falling into the holes and blocking light to the sensors.

Laboratory Design

As a result of difficulties encountered in subject recruitment, data collection took place in two different locations. At both testing sites, however, the laboratory was set-up in an identical manner. Rear and side views of the basic laboratory set-up are presented in Figures 14 and 15.

To permit indoor use of the golf system, a framework (i.e., cage) was designed so that fishing net (holes approximately one inch in dimension) could be attached at the rear, the top, and both sides of the framework. Precautionary measures were also implemented in laboratory set-up to ensure the physical safety of participants on shots going off the heel or toe of the golf club. In location one, the netting on both sides of the cage were extended beyond the length of the cage, flaring out to the sides at approximately 45°, and secured to permanent structures at the side of the room (i.e., the wall of the laboratory). In location two, wood boards were secured on the side walls in a manner such that shank balls were deflected away from the performer into the safety framework.

In an attempt to control the experimental setting so that participants were restricted to only sensory feedback produced at ball impact, flight trajectory and location of ball impact on the net were occluded from participants' vision. To accomplish this, a dark canvas tarp and black poly strips were used at the front of the framework. First, a canvas tarp was secured at the top of the framework and allowed to hang down. The bottom of the tarp was lifted up approximately one metre off the ground, and secured with ropes to the framework. Two rows of black poly strips were then attached to the front of the framework so that they hung from the middle of the tarp to the ground. The tarp served to occlude participant vision from the roof of the cage-like set-up to the middle of the hitting space; whereas, the poly strips occluded participant vision from the

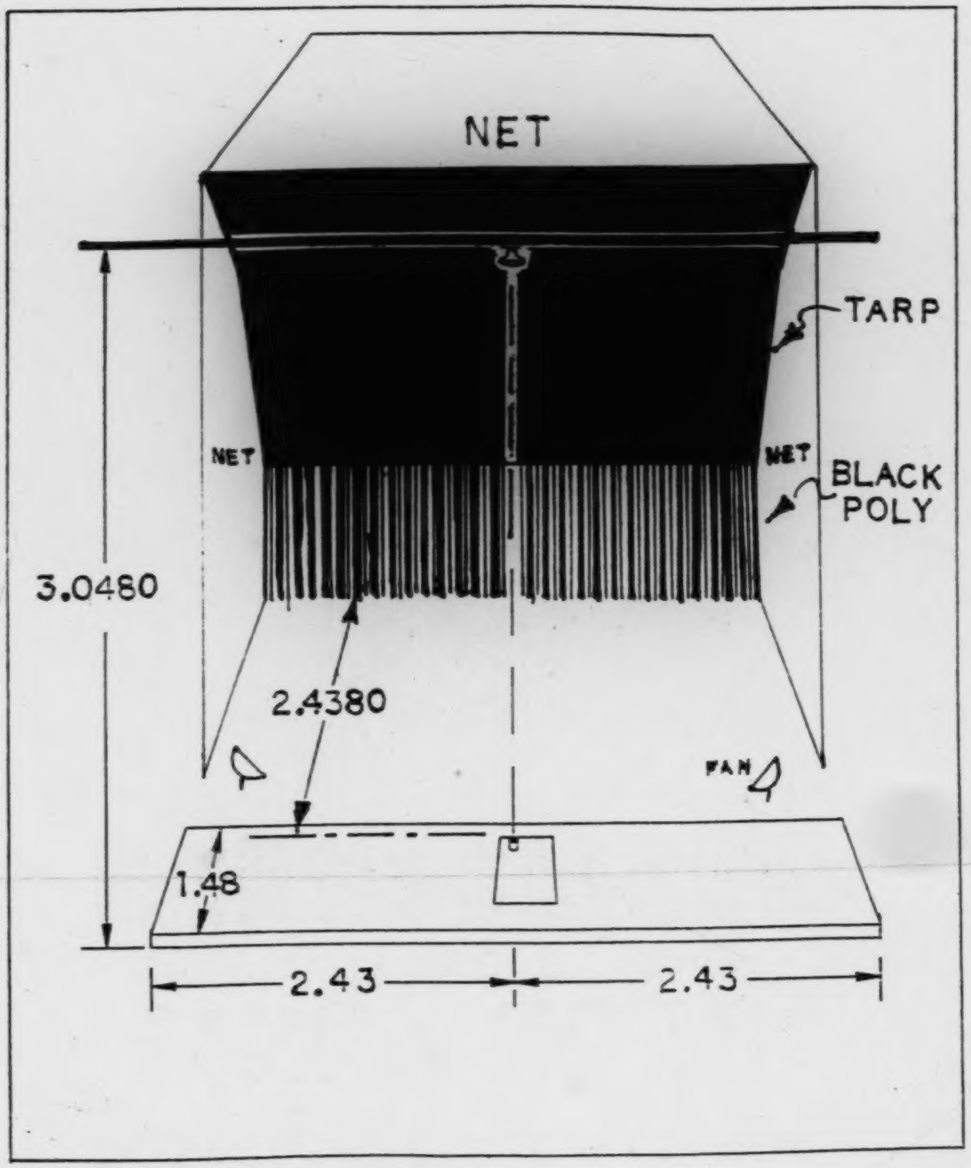
NET
TARP
NET
NET
BLACK POLY
3.0480
2.4380
FAN
1.48
2.43
2.43

Figure 14. Rear view of basic laboratory design.

Note: All measurements reported in metres.

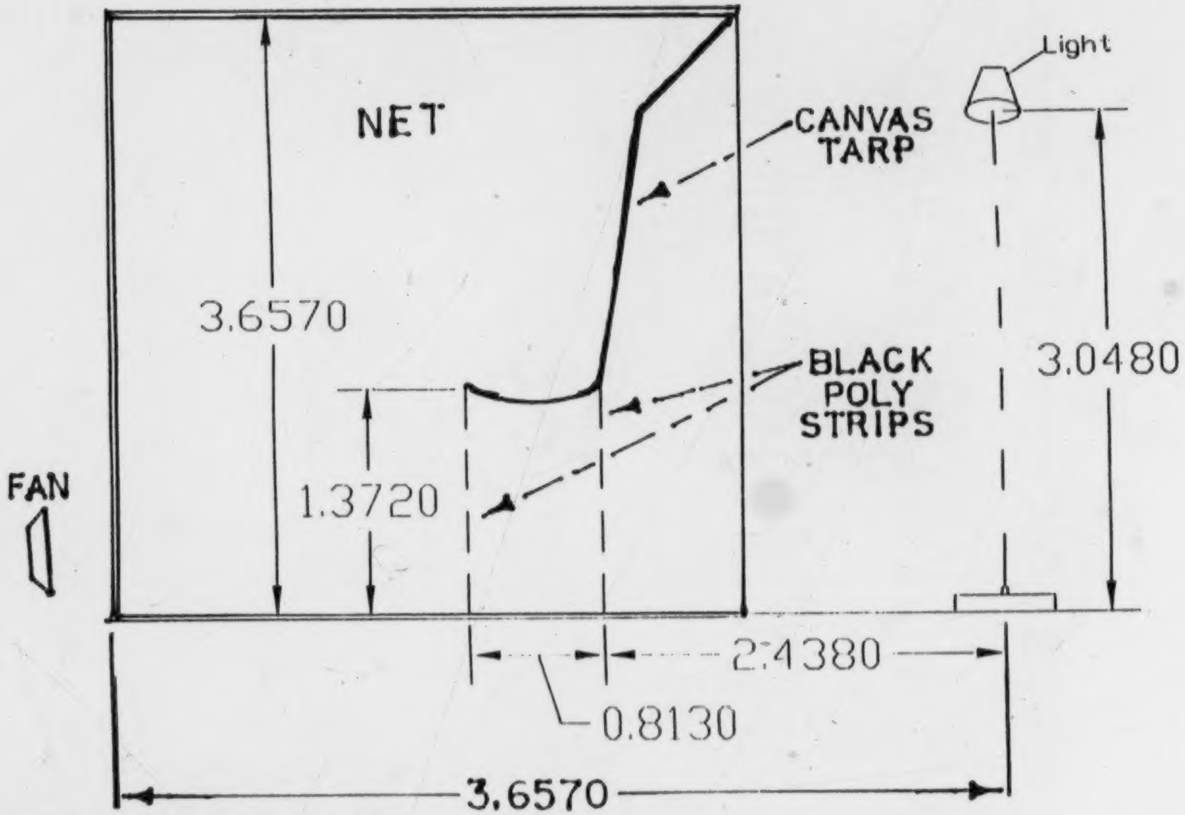
NET
CANVAS TARP
BLACK POLY STRIPS
Light
FAN
3.6570
1.3720
3.0480
0.8130
2.4380
3.6570

Figure 15. Side view of basic laboratory design.

Note: All measurements reported in metres.

middle of the hitting space to the ground.

The purpose of the poly strips was to permit passage of the ball through the imposed vision barrier and served as the rationale for lifting the canvas tarp off the ground. This design implementation is significant in that allowing passage of the ball not only prevents the participant from gaining information regarding flight trajectory but it prevents a participant from acquiring knowledge regarding the ball's point of impact on the net. If the ball was not allowed to pass through the vision barrier, the participant may deduce certain parameter aspects from merely recognizing the point at which the ball hits the tarp. Since a cleanly hit golf ball starts low to the ground and gradually rises, the black poly strips did not originate higher than the middle of the hitting space. On shots hit underneath the golf ball, the canvas tarp served a safety function by deadening the ball upon impact.

To ensure that participants could not see through the black poly strips, fans were strategically placed so that when they were turned on and directed at the poly strips, the strips were in a constant state of flux eliminating sight beyond the poly strip barrier. In addition, the secured portion of the canvas tarp served to darken the background and completely eliminate vision of ball landing location. To darken the background in the room, the laboratory lights were also shut off which contributed to the efficiency of the black poly strips for occluding participant vision. Although the laboratory lights were shut off, it should be noted that the performance of the participant was not disrupted since the light source used to operate the Pro V system shed enough light for the participant to execute his swing.

A 120 Watt indoor reflector spotlight was used as the Pro V light source and was mounted on a ceiling beam directly above the tee of the hitting mat. It is important to note that an indoor spotlight was used as the light source rather than an outdoor flood lamp. Outdoor lamps possess a heavy cut glass lens; whereas, an indoor spotlight has a smooth lens which produces more light and a sharper shadow of the golf club when compared to an outdoor lamp (GolfTek, 1998).

The Pro V data cable was extended to the rear of the room and connected to a computer equipped with the GolfTek PF-123 Graphics Program™. The computer system was placed to the rear of the Pro V hitting mat to decrease the danger of a golf ball or club hitting the computer hardware during the experimental session.

Data Collection Procedure

The experimental session was broken up into three phases: the Familiarization phase, the Testing phase, and a Debriefing phase (refer to Figure 16 for design of experimental session). Each of these phases is described below.

Familiarization Phase. Upon entering the laboratory, participants were asked to read and sign the informed consent form (refer to Appendix A). After giving consent and asking participant questions, each golfer was provided with a can of balls and given the opportunity to familiarize himself with the testing apparatus and to physically warm-up. During this time, the experimenter completed the final preparations for the testing session by selecting the golfer's swing handedness (right or left) and the appropriate wood (driver or three wood) and clubhead size (standard, midsize, or jumbo) on the GolfTek P-123 Golf Program™. It should be noted that prior to warm-up, participants were informed that

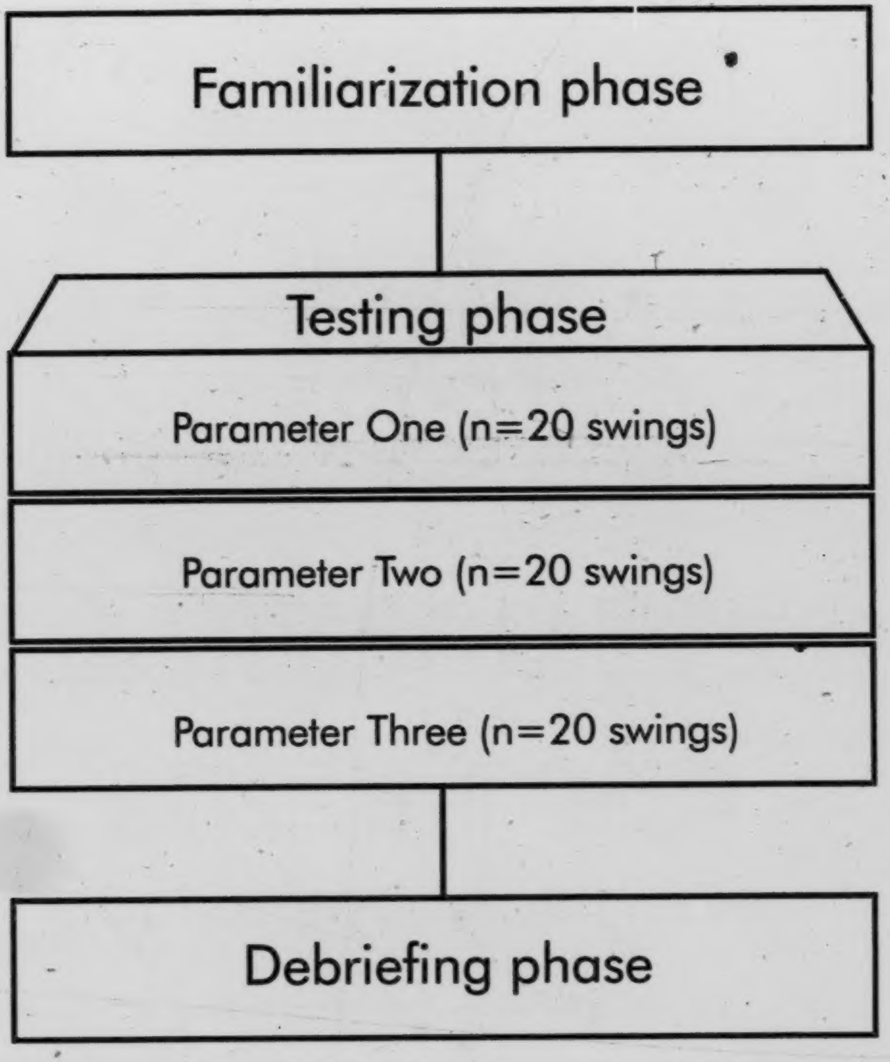
Familiarization phase
Testing phase
Parameter One (n=20 swings)
Parameter Two (n=20 swings)
Parameter Three (n=20 swings)
Debriefing phase

Figure 16. Overview of experimental session for Study Two.

it was their choice as to whether they used their driver or three wood for the testing session; however, once a club was chosen, participants were told that they were required to use the chosen club for the entire duration of testing. Each participant was allowed as much time as he wished to warm-up on the apparatus, and when he felt he was ready to begin, the experimenter was informed and the testing phase of the session commenced.

Testing Phase. All golfers were requested to perform three sets of 20 golf balls. For all 60 swings, participants were instructed to hit the ball just as they would hit it on a tee at the driving range or on the golf course. For each set, participants were asked to focus on one of the aforementioned swing parameters (CA, IP, or SP), the order of which was randomized for all golfers. After each swing, the participant was requested to verbally report his performance on the parameter of focus according to a seven choice parameter scale. Figures 17, 18, and 19 illustrate the parameter scale used for each clubface aspect (CA, IP, and SP, respectively).

If, for example, the parameter of focus was impact point, the participant was requested to identify whether he had struck the ball with the heel, centre, or toe of the club. If the participant perceived the impact point to be on the heel or toe of the clubface, he was asked to report whether he had struck the ball 'slightly', 'moderately', or 'largely' on the heel or toe. During testing instructions, the participant was informed that it was his perception of what 'slightly', 'moderately', and 'largely' were, but was presented a set of seven diagrams (refer to Appendix B) on the laboratory wall, and asked to use these diagrams for constructing an operational definition of the three deviation descriptors. The procedure for clubface angle and swing path were identical to the example presented

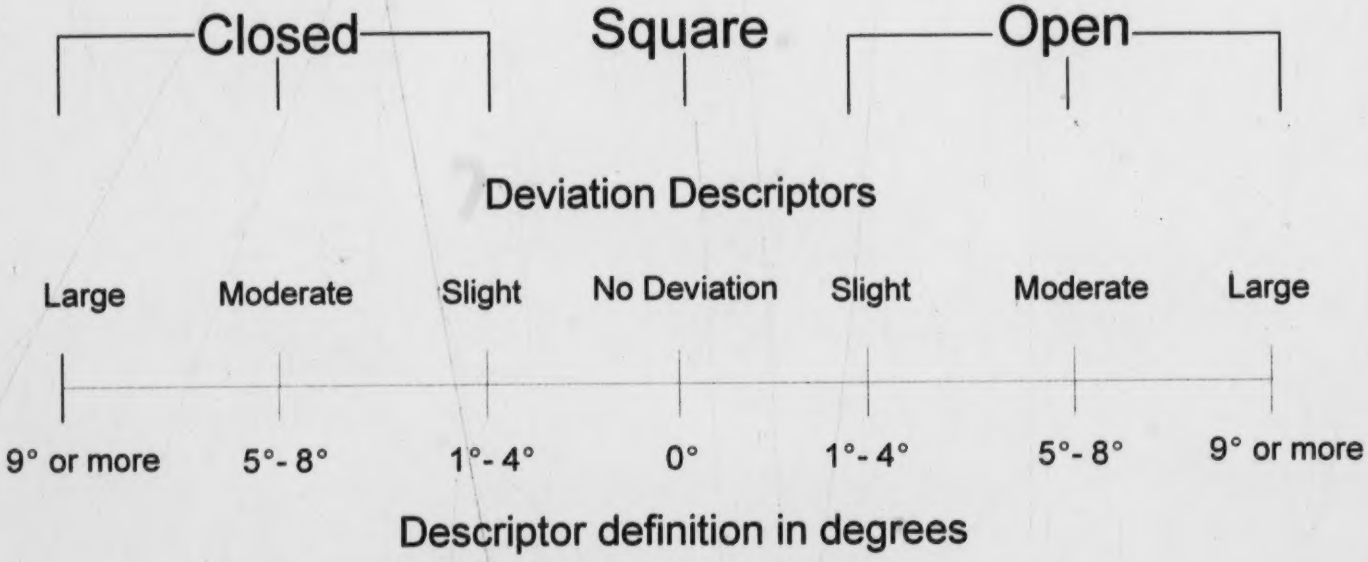
Closed
Square
Open
Deviation Descriptors
Large
Moderate
Slight
No Deviation
Slight
Moderate
Large
9° or more
5°- 8°
1°- 4°
0°
1°- 4°
5°- 8°
9° or more
Descriptor definition in degrees

Figure 17. Seven choice parameter scale for clubface angle (CA).

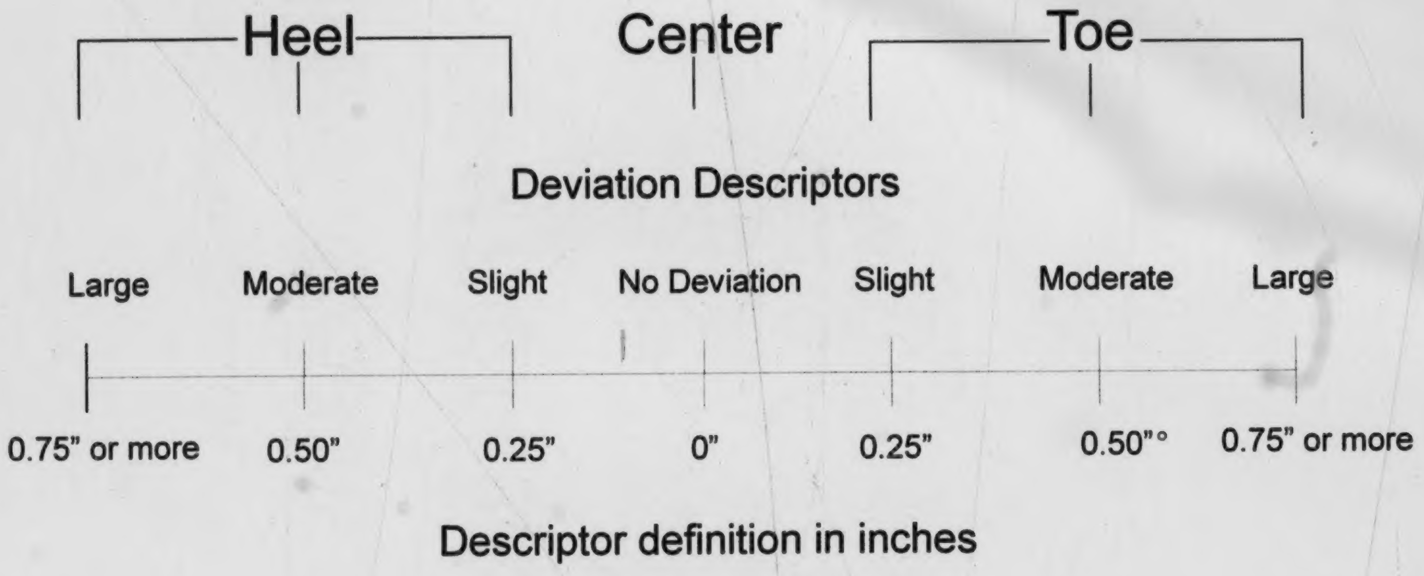
Heel
Center
Toe
Deviation Descriptors
Large
Moderate
Slight
No Deviation
Slight
Moderate
Large
0.75” or more
0.50”
0.25”
0”
0.25”
0.50”
0.75” or more
Descriptor definition in inches

Figure 18. Seven choice parameter scale for impact point (IP).

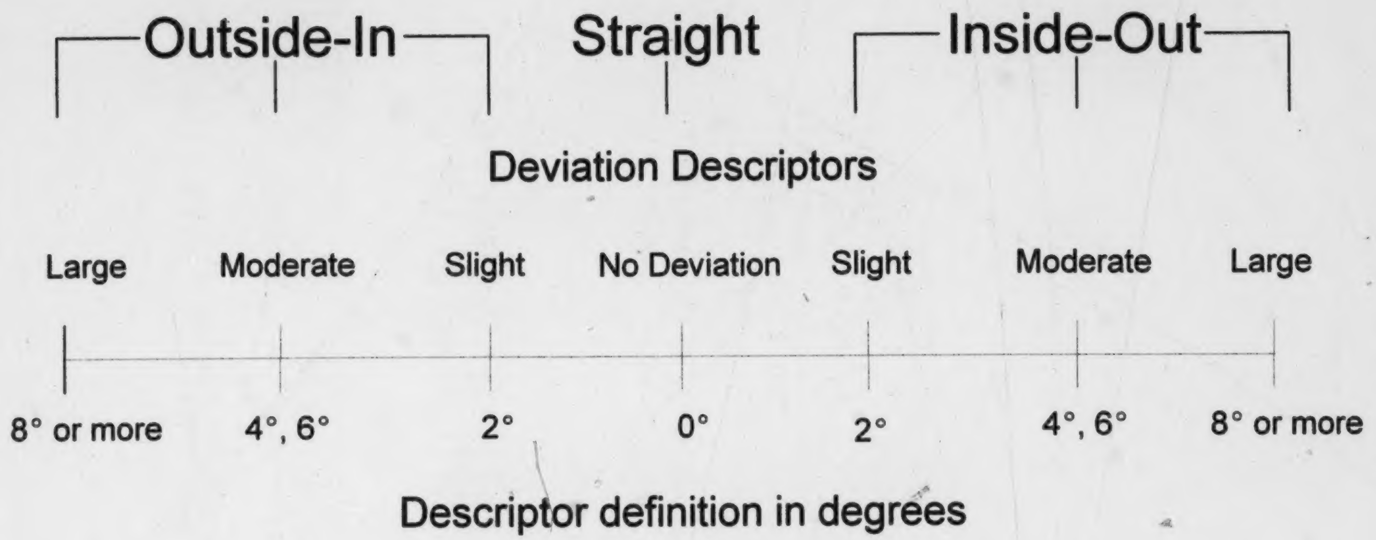
Outside-In
Straight
Inside-Out
Deviation Descriptors
Large
Moderate
Slight
No Deviation
Slight
Moderate
Large
8° or more
4°, 6°
2°
0°
2°
4°, 6°
8° or more
Descriptor definition in degrees

Figure 19. Seven choice parameter scale for clubhead swing path (SP).

above with only the wording of the question adapted to fit the particular parameter of focus (i.e., Did you strike the ball with an open, closed or square clubface? If the clubface was open or closed, was it slightly, moderately or largely open/closed? and; Did you swing the clubhead inside-out, outside-in, or straight? If the swing path was inside-out or outside-in, was it slightly, moderately, or largely inside-out/outside-in?). It should be noted that participants were given the freedom to verbally report their judgements of performance quantitatively (e.g., degrees, inches) or they could verbally estimate their performance using the three deviation descriptors (slightly, moderately, or largely).

Actual performance results were not released to the participant at any time during the duration of the 60 swings required to complete the testing procedure. At the end of every block of 20 swings, each participant received a short break in which he had an opportunity for refreshment. As the participant was resting, instruction regarding the parameter of focus for the following set of 20 swings was presented. During the testing session, fat hits or shank balls were discarded from the data set. Fat hits tend to produce erroneous readings because the clubhead contacts the ground (hitting surface of the Pro V mat) before the ball which, causes the analyzer to vibrate. Shank balls also produce erroneous readings because the ball is struck with the neck or the 'shank' of the club and essentially, the face of the club fails to make contact with the ball.

Debriefing Phase. At the end of the testing session, each participant received a computer print-out displaying the actual parameter measurements (participant swing profile) for every swing executed by the participant in the study. A brief discussion explaining the computer print-out was provided at this time, and the participant was given the opportunity to ask any questions regarding the nature of the study.

Data Analysis

Motor Performance. To determine if any significant difference in motor performance existed between the LOW and HIGH groups, mean motor performance was calculated for each participant on all three swing parameters using performance measurements obtained from the GolfTek Pro V Swing Analyzer™. A test of central tendency was run to determine the mean motor performance for both LOW and HIGH groups. Mean performance of groups was compared using an independent t-test ($\propto = .05$).

During the acquisition of a closed motor skill, one major change that occurs as a function of practice is the consistency with which the performer executes the movement. As proficiency in skill is acquired, performers produce movement patterns of greater consistency and adaptability (Abernethy et al., 1993). To determine the performance variability of each group, the standard deviation was calculated for each participant on all three swing parameters and a test of central tendency was run to determine the mean standard deviation for both LOW and HIGH groups. To determine if any significant difference existed between the low and high handicap groups for variability in motor performance, mean standard deviations of groups were compared using an independent t-test ($\propto = .05$).

Judgements of Performance Error. To calculate error scores, a participant's perceived score was compared to his actual performance score, the latter of which was referred to as the criterion. The variable of interest, was the error or deviation between an individual's estimation of performance and his actual performance score. The less deviation, the more accurate the individual's perception was of his performance. Two different error scores, absolute error (AE) and total variability (E), were calculated for each parameter of focus (CA, IP and SP), and differences between the low and high handicap groups were assessed using independent t-tests ($\propto = .05$).

Absolute error (AE)[1]. The first error score, absolute error (AE), was used as a general measure of magnitude or amount of judgement error (Magill, 1993). As such, absolute error measured overall judgement accuracy and was the absolute deviation (without regard to direction) between the participant's responses and his actual motor performance scores. Mean absolute error was calculated from the following equation:

$$\text{Absolute error} = \frac{\sum_{i=1}^{n} |x_i - \text{Criterion (Actual) Score}|}{n}$$

where x_i, is the participant's perceived score on swing *i*, and *n* is the number of swings the participant performed (Schmidt, 1988, p. 59). To obtain a difference or deviation score between a participant's perceived score (x_i) and his criterion score on a particular trial, the participant's perceived score and his actual motor performance measurement was converted to a score ranging on a continuum from one to seven (Table 5). For example, if a participant reported that he had struck the ball slightly on the heel of his club (-0.25") on his seventh trial, his perceived score for swing x_7 would equal a score of three on the continuum scale. For that particular swing, let us suppose that the sensors on the Pro V hitting mat registered his impact point to be moderately on the toe of his clubhead (0.50"). The participant's motor performance score for this trial would equate itself to a score of six on the continuum scale. Without regard to the direction of error, the deviation between the participant's estimate of performance and the criterion score is three.

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[1] Traditionally, absolute error (AE) and total variability (E) have been used as error scores in research settings where the criterion score was thought of as the movement goal. In these studies, the criterion was identical for each trial executed and the individual's actual performance was compared to this criterion. For this project, the criterion score for both AE and E, were represented in a slightly different manner. Setting a movement goal was not pertinent to the investigation focus of this study, and therefore, AE and E were calculated using the participant's actual performance score as the criterion score. Although a participant's actual score could be different for every trial executed, it was still considered to be the criterion as the participant was being evaluated for the degree of accuracy between his estimated score and the actual score (criterion).

***Total variability (E)*^{1}.** A second error score, total variability (E), was calculated to determine the total amount of "spread" of the participant's responses around the actual score for each set (CA, IP, and SP) of responses. The overall accuracy in responding was calculated from the formula:

$$\text{Total variability} = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \text{Criterion (Actual) Score})^2}{n}}$$

where x_i and n are defined as before (Schmidt, 1988, p. 59). Often referred to as the *root mean squared error*, total variability represents accuracy with respect to the target since it is based on the sum of a group of squared differences, where each difference is the amount by which the participant missed the target. In this case, target refers to one's actual performance score. To calculate total variability, both the participant's estimate of

Table 5

Continuum Scale used to Convert Performance Judgements and Motor Performance Scores on Clubface Angle (CA), Impact Point (IP), and Swing Path (SP) for the Calculation of Absolute Error (AE) and Total Variability (E)

Parameter	**Continuum Score**						
	1	**2**	**3**	**4**	**5**	**6**	**7**
CA							
Verbal Estimate using Degrees	-9° or more	-5° to -8°	-1° to -4°	0°	1° to 4°	5° to 8°	9° or more
Verbal Estimate using Parameter Descriptors	Large	Moderate	Slight	Square	Slight	Moderate	Large
Motor Performance Score	-9° or more	-5° to 8°	-1° to -4°	0°	1° to 4°	5° to 8°	9° or more

Table 5 Continued

Parameter	Continuum Score						
	1	2	3	4	5	6	7
IP							
Verbal Estimate using Inches	-0.75"	-0.50"	-0.25"	0"	0.75"	0.50"	0.25"
Verbal Estimate using Parameter Descriptors	Large	Moderate	Slight	Centre	Slight	Moderate	Large
Motor Performance Score	-0.75"	-0.50"	-0.25"	0"	0.75"	0.50"	0.25"
SP							
Verbal Estimate using Degrees	-8° or more	-4° to -6°	-2°	0°	2°	4° to 6°	8° or more
Verbal Estimate using Parameter Descriptors	Large	Moderate	Slight	Straight	Slight	Moderate	Large
Motor Performance Score	-8° or more	-4° to -6°	-2°	0°	2°	4° to 6°	8° or more

performance and his actual motor performance were converted to a score ranging from one to seven on the continuum scale previously described.

Results

Motor Performance. Analysis of mean performance revealed no statistically significant difference between the LOW and HIGH group with regards to motor performance for CA (0.43 vs 0.48 deg, respectively), IP (-0.12 vs -0.12 in., respectively), and SP (2.57 vs 1.12 deg, respectively). These data indicate that motor performance of both LOW and HIGH groups were similar for all clubface swing dimensions.

Analysis of mean standard deviation for CA motor performance rendered a statistically significant difference between the LOW (mean SD = 5.39 deg) and the HIGH (mean SD = 7.37 deg) handicap groups, $t(18) = -2.99$, $p < .01$. Analysis of the mean standard deviation for IP motor performance also revealed a statistically significant difference between LOW (mean SD = 0.32 in.) and HIGH (mean SD = 0.44 in.) handicap groups, $t(18) = -2.96$, $p < .01$. These data indicate that participants in the low handicap group performed with significantly greater consistency on CA and IP swing parameters than the high handicap group. However, analysis of SP motor performance did not yield a statistically significant difference between LOW and HIGH groups. The mean standard deviation for the LOW group was 2.25 deg, while the mean standard deviation for the HIGH group was 3.01 deg. Therefore, the LOW group did not perform with significantly greater motor performance consistency on the SP dimension than the HIGH group.

The mean and standard deviation values for CA, IP, and SP regarding actual motor performance scores are displayed in Table 6 for the participant sample. In addition, a sample of participant performance scores for all three swing parameters (CA, IP, and SP) are presented in Figures 1-6 (Appendix C).

Table 6

Participant Mean and Standard Deviation for Motor Performance of Clubface Angle (CA), Impact Point (IP), and Swing Path (SP), Study Two

	Participant	Clubface Angle (degrees)		Impact point (inches)		Swing Path (degrees)	
		Mean	SD	Mean	SD	Mean	SD
Low Handicap Group	1	1.75	4.28	-0.20	0.28	6.60	1.12
	2	3.87	8.52	-0.33	0.45	6.60	3.46
	3	-4.97	5.11	-0.21	0.19	1.23	3.02
	4	-7.73	5.14	-0.30	0.32	-6.53	1.80
	5	-0.42	6.75	0.22	0.36	-7.57	3.57
	6	4.62	5.26	-0.11	0.35	6.13	1.72
	7	3.00	4.32	-0.13	0.32	7.43	2.33
	8	-2.25	5.95	0.00	0.34	2.30	1.64
	9	0.52	4.74	-0.24	0.29	3.97	2.28
	10	5.95	3.78	0.10	0.28	5.53	1.53
Mean		**0.43**	**5.39**	**-0.12**	**0.32**	**2.57**	**2.25**
High Handicap Group	11	-9.22	4.93	-0.42	0.21	-2.40	3.97
	12	-3.43	7.48	-0.50	0.32	-3.83	1.96
	13	6.67	7.45	-0.26	0.48	3.97	3.28
	14	-3.33	7.17	-0.04	0.45	8.72	2.71
	15	4.03	8.36	0.25	0.49	2.62	4.19
	16	7.22	8.25	0.14	0.58	2.03	1.78
	17	-0.38	10.61	0.19	0.54	1.23	3.66
	18	7.70	7.50	0.19	0.40	-0.03	2.22
	19	0.87	6.26	-0.38	0.46	-1.63	3.11
	20	-5.32	5.72	-0.33	0.44	0.53	3.21
Mean		**0.48**	**7.37**	**-0.12**	**0.44**	**1.12**	**3.01**

Judgements of Performance Error.

Absolute error (AE): Analysis of the CA data revealed no statistically significant difference between low and high handicap groups with regards to AE scores (mean AE =1.44 vs 1.67 deg, respectively). No statistically significant difference was also found between LOW and HIGH for AE scores on the SP swing dimension (mean AE = 1.42 vs 1.38 deg, respectively). These data suggest that participants in the LOW handicap group did not display less absolute error in judgements of motor performance than the HIGH group for CA and SP. Although it is not a statistically significant difference, the HIGH group actually displayed less error in judgement than the LOW group (mean AE = 1.42 vs 1.38 deg, respectively) for the SP variable. Figures 20 and 21 provide a visual representation of these findings.

In contrast, analysis of the IP data revealed that LOW, in comparison to HIGH, displayed statistically significant lower AE scores (mean AE = 0.96 vs 1.54 in., respectively), $t(18) = -2.70$, $p < .05$. This implies that participants in the LOW handicap group displayed less absolute error in judgements of motor performance than the HIGH group for IP. This finding is visually presented in Figure 22.

A summary of absolute error (AE) values for each study participant are displayed in Table 7.

Total variability (E). Analysis of the CA data revealed no statistically significant difference between the LOW and HIGH handicap groups with regards to E scores (mean E = 1.72 vs 1.92 deg, respectively). No statistically significant difference was also found between LOW and HIGH for E scores on the SP dimension (mean E = 1.67 vs 1.75 deg,

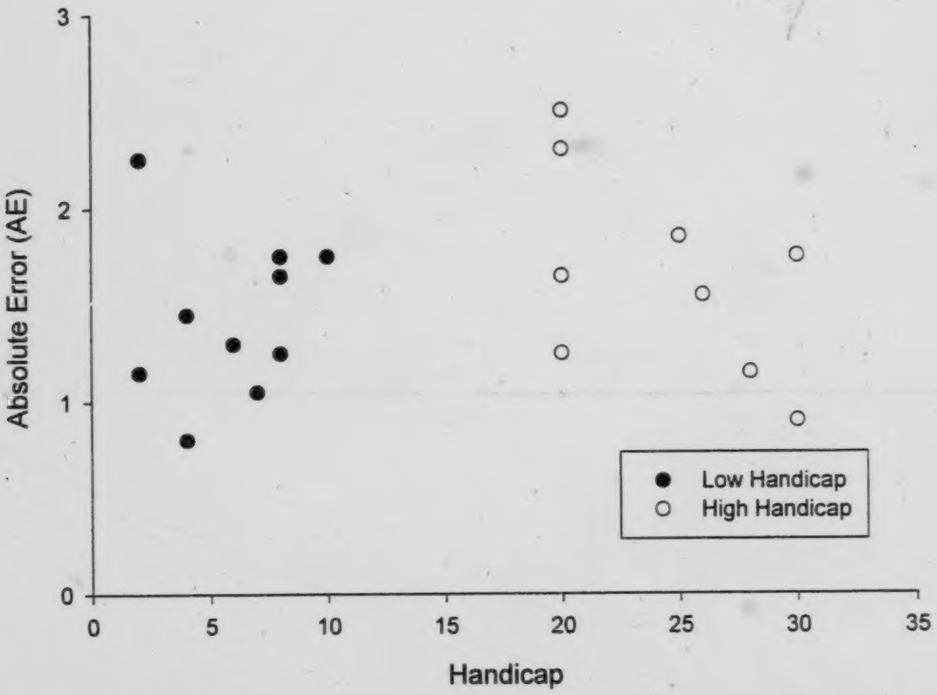

Figure 20. Mean absolute error (AE) for performance judgement of Clubface angle (CA) as a function of participant handicap, Study Two.

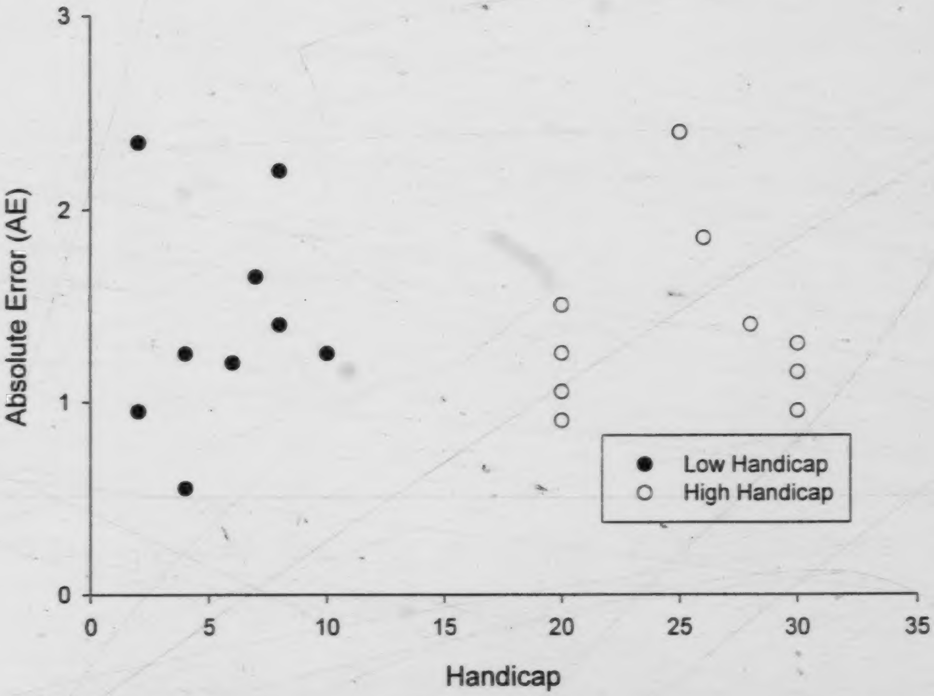

Figure 21. Mean absolute error (AE) for performance judgement of Clubhead swing path (SP) as a function of participant handicap, Study Two.

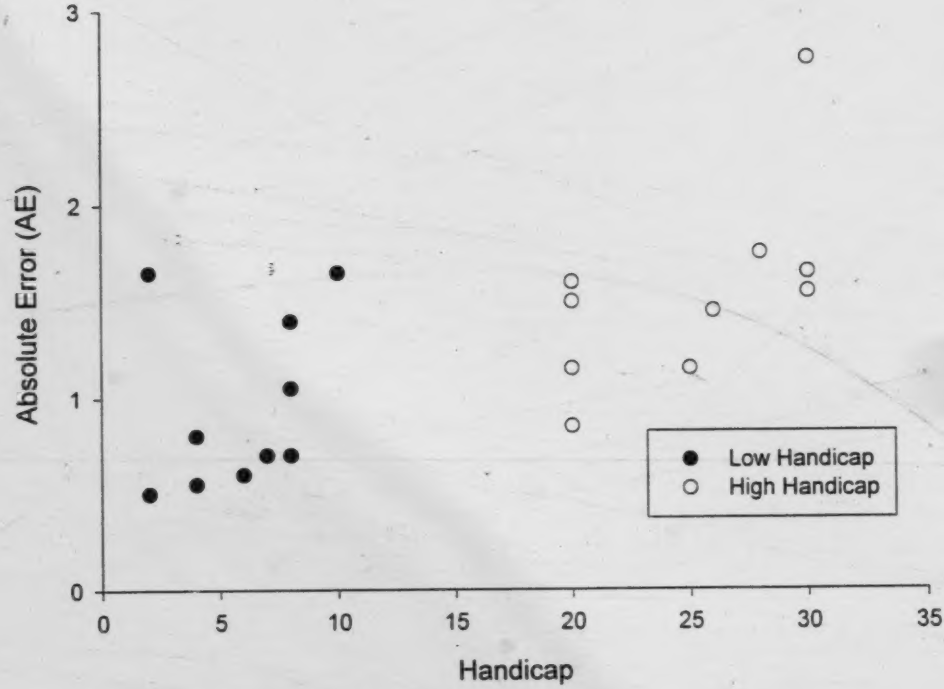

Figure 22. Mean absolute error (AE) for performance judgement of Impact point (IP) as a function of participant handicap, Study Two.

Table 7

Mean Absolute Error (AE) for Performance Judgement of Clubface Angle (CA), Impact Point (IP), and Swing Path (SP), Study Two

	Participant	Clubface Angle (CA)	Impact Point (IP)	Swing Path (SP)
Low Handicap Group	1	0.80	0.55	0.55
	2	1.75	1.65	1.25
	3	1.30	0.60	1.20
	4	1.75	1.05	1.40
	5	1.25	1.40	2.20
	6	1.05	0.70	1.65
	7	2.25	0.50	2.35
	8	1.65	0.70	1.40
	9	1.15	1.65	0.95
	10	1.45	0.80	1.25
Mean		**1.44**	**0.96**	**1.42**
SD		**0.42**	**0.45**	**0.54**
High Handicap Group	11	1.26	1.15	2.40
	12	1.86	1.75	1.40
	13	1.73	2.75	1.30
	14	1.86	1.15	1.50
	15	1.47	1.45	1.85
	16	1.32	1.50	1.25
	17	2.66	1.60	0.90
	18	1.91	0.85	1.05
	19	1.40	1.65	0.95
	20	1.63	1.55	1.15
Mean		**1.67**	**1.54**	**1.38**
SD		**0.49**	**0.51**	**0.46**

respectively). These results suggest that participants in the LOW group did not display less total variability in judgements of movement production accuracy than the HIGH group for CA and SP. These results are visually illustrated in Figures 23 and 24.

Analysis of the IP data revealed that LOW, in comparison to HIGH, had statistically significant lower E scores (mean E = 1.18 vs 1.92 in., respectively), $t(18) = -3.15$, $p < .01$. This suggests that participants in the LOW handicap group displayed less total variability in judgements of movement production accuracy than the HIGH group for IP. This finding is displayed in Figure 25.

A summary table presenting total variability (E) values for each participant regarding E are displayed in Table 8.

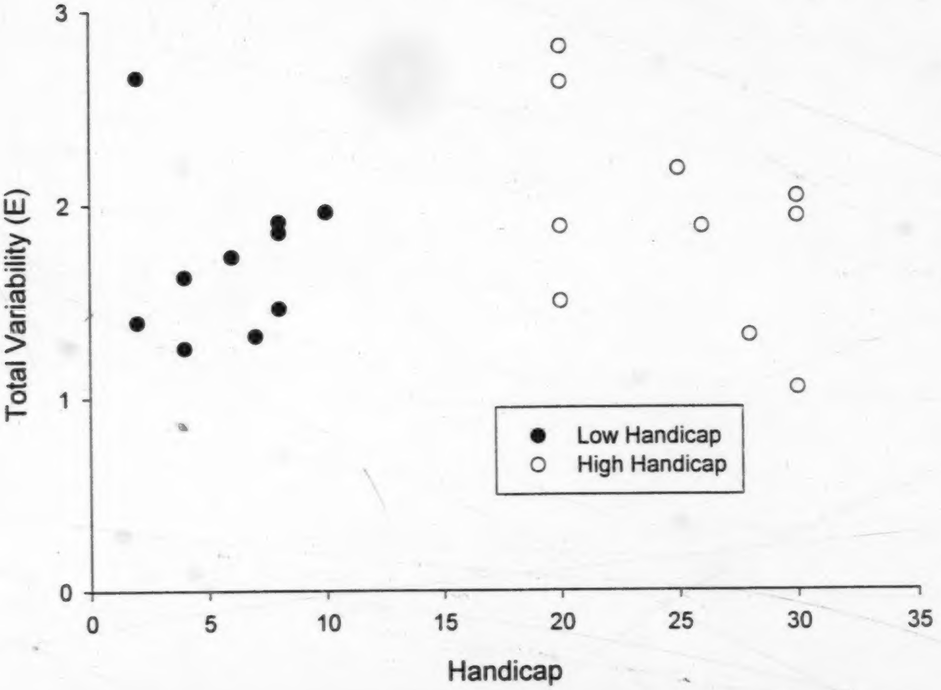

Figure 23. Mean total variability (E) for performance judgement of Clubface angle (CA) as a function of participant handicap, Study Two.

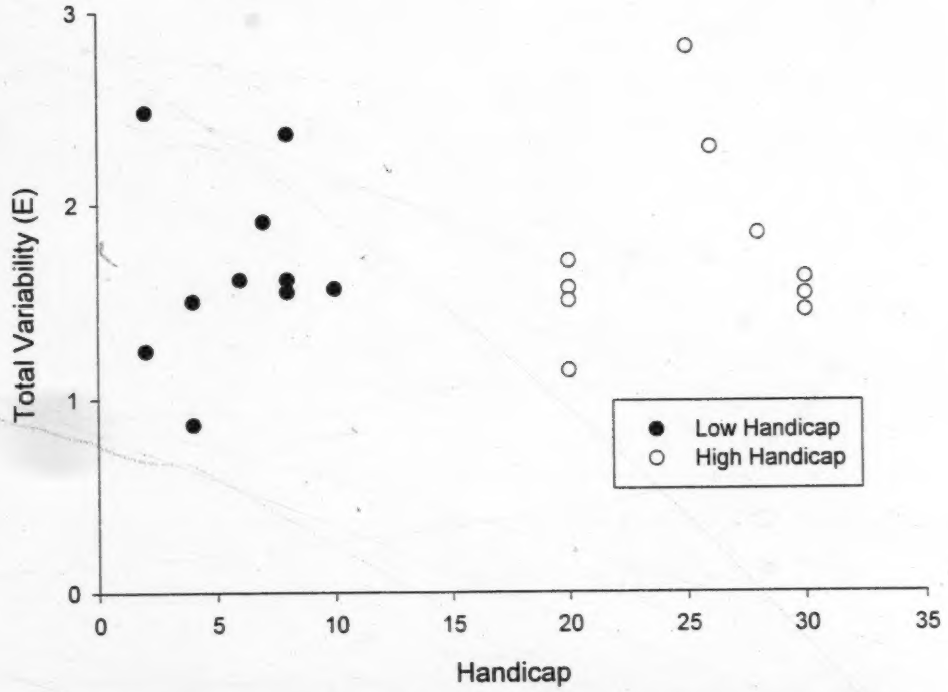

Figure 24. Mean total variability (E) for performance judgement of Clubhead swing path (SP) as a function of participant handicap, Study Two.

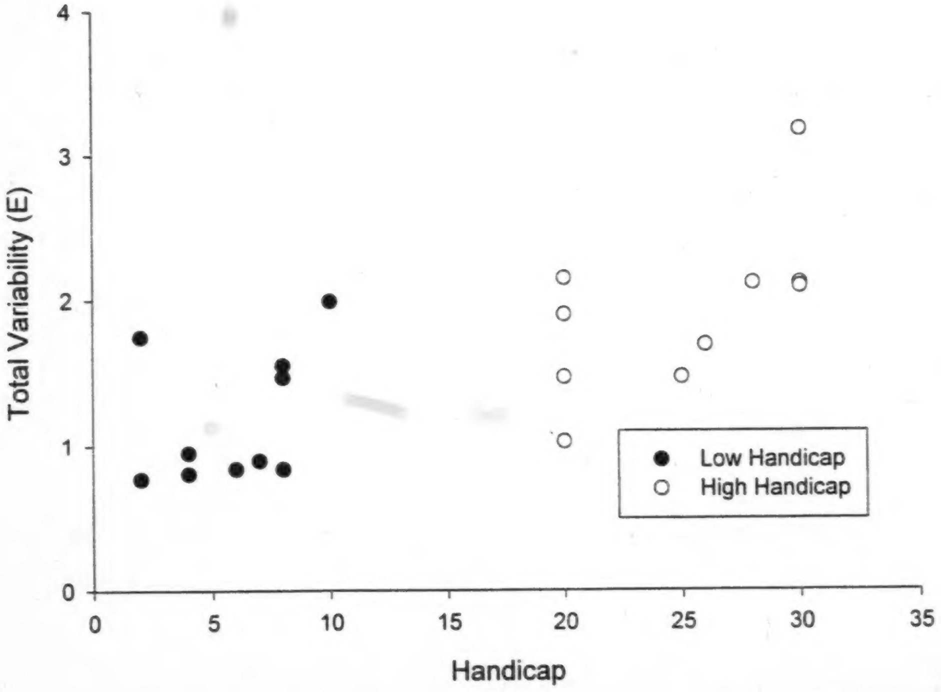

Figure 25. Mean total variability (E) for performance judgement of Impact point (IP) as a function of participant handicap, Study Two.

Table 8

Mean Total Variability (E) for Performance Judgement of Clubface Angle (CA), Impact Point (IP), and Swing Path (SP), Study Two

	Participant	Clubface Angle (CA)	Impact Point (IP)	Swing Path (SP)
Low Handicap Group	1	1.26	0.81	0.87
	2	1.96	1.99	1.57
	3	1.73	0.84	1.61
	4	1.86	1.47	1.55
	5	1.47	1.55	2.37
	6	1.32	0.89	1.91
	7	2.66	0.77	2.48
	8	1.91	0.84	1.61
	9	1.40	1.75	1.24
	10	1.63	0.95	1.50
	Mean	**1.72**	**1.18**	**1.67**
	SD	**0.41**	**0.46**	**0.48**
High Handicap Group	11	2.18	1.47	2.81
	12	1.32	2.11	1.84
	13	1.05	3.17	1.45
	14	1.88	1.47	1.70
	15	1.88	1.69	2.29
	16	1.50	1.90	1.57
	17	2.81	2.14	1.14
	18	2.63	1.02	1.50
	19	2.04	2.11	1.16
	20	1.94	2.09	1.53
	Mean	**1.92**	**1.92**	**1.75**
	SD	**0.54**	**0.58**	**0.48**

Discussion

In conducting the present experiment, the primary objective was to determine whether low handicap golfers exhibit superior judgements of movement production accuracy than high handicap golfers when asked to report on clubface features immediately following swing execution. In motor behaviour literature, it is generally accepted that performers in the final stages of skill acquisition possess a greater capability for detecting their own errors when compared to novices (Fitts & Posner, 1967, Gentile, 1972). This would imply that individuals possessing superior skill should also exhibit a greater correspondence between what they perceive to be occurring and the empirical reality of what is actually occurring. Therefore, the low handicap group should exhibit a greater congruity between their perceived performance score and their actual performance score as compared to the high handicap group regarding clubface swing dimensions: CA, IP, and SP. The results of the present experiment render mixed support for this notion since the LOW group displayed less absolute error and total variability in judgement than the HIGH group for only one of the three clubface parameters. The accuracy with which, participants estimated their performance for the IP variable increased for those performers in the low handicap group (Figures 22 and 25). However, an increase in estimate accuracy for CA and SP variables was not exhibited by golfers possessing a low handicap when compared to those possessing a high handicap (Figures 21, 23, 24, and 26).

One leading interpretation of these findings pertains to the role that each clubface aspect plays in the execution of a successful golf shot. If you refer back to discussion regarding clubface aspects of the golf swing (see Chapter 3), you will note that IP is the clubface parameter responsible for the *distance* a ball travels; whereas, CA and SP are factors that interact to dictate the *direction* (flight trajectory) of a shot. Considering that CA and SP swing attributes serve a function distinct to the role IP plays in controlling a golf shot, it is possible that performers discriminate between sensory sources and utilise the source that elicits the most appropriate or reliable error detection information for each clubface aspect. For example, *feeling* the shaft vibrate when hitting the ball on the heel of the club may render the golfer more useful information for the detection of impact location errors than actually *seeing* the distance the ball travels. One of the best sources of information concerning flight characteristics or direction of a ball, is vision of the trajectory path (Fischman & Schneider, 1985); therefore, *seeing* the flight path of the ball may surface as a more reliable information source for detecting direction errors than *feeling* the clubface open or close. Such a suggestion implies that response-produced feedback is weighted then sought after and utilised in accordance to its reliability (Howarth, 1978). Since we possess limited capacity to process information and it is difficult to know, predict, and control the positions of our body during the execution of a complex motor activity, it is possible that performers attempt to employ the most efficient method (strategy) for securing reliable sensory information on which perceptions of performance are based.

For the golf swing, contributions made by error detection mechanisms most likely occur after the response has been made. In light of the above example, viewing a ball's flight trajectory may be a primary strategy which performers use to obtain reliable CA and SP information for performance evaluation. Since golfers are afforded the opportunity to watch the flight trajectory of their ball, visual information may be used to analytically deduce certain parameter aspects. For example, after the execution of a swing, a golfer may see his ball hook to the left. If the golfer possesses a certain degree of domain specific knowledge he may conclude that his swing error was caused by an in to out path or closed clubface. In contrast, viewing the ball slice violently to the right, the golfer may analytically deduce that an outside-in swing path or an open clubface may be the cause of the swing error. However, using details obtained from trajectory of the ball as a primary source of information would not be readily used for formulating IP performance estimates unless the golfer was to mishit or "shank" the ball directly to the right.

In this study, flight trajectory of the ball was occluded from participant vision. As a consequence, it is possible that a primary source of response-produced feedback for formulating CA and SP performance estimates was inaccessible to the performer. In fact, during the testing session, it was noted that participants often commented before the set began, or within the first few trials of a set, that assessment of CA and SP performance would be or was rather difficult since they could not see where the ball was going. Participants did not, however, make such comments when they were asked to focus on IP for the trial set of 20 swings. Although these findings suggest that watching a ball's flight trajectory may be a commonly used method of procuring swing information for the detection of error, it is important to note that this suggestion does not imply that participants did not or cannot use other sensory sources (e.g., proprioception) to formulate performance perceptions regarding CA and SP parameters. Rather, it is proposed that by eliminating a primary source of feedback, the performer experienced difficulty comparing actual response feedback against the expected sensory consequence or reference standard. As such, error signals were not detected or converted into a reportable form (subjective reinforcement) by the low handicap group with as much accuracy for CA and SP as the LOW group displayed for the detection and labelling of error signals for the IP variable. Such a suggestion would support the notion that error detection, like movement learning, is relatively specific to the feedback condition under which practice occurs. The more practice one has utilising a particular feedback source, the more important that feedback source becomes in the detection of error and ultimately for the control of movement. That is, if a golfer predominately uses vision of ball flight trajectory to detect movement errors in CA and SP swing attributes, the more important vision becomes as a response-produced feedback source in the detection and correction of swing errors.

When important sensory information is eliminated as a source of information, existing literature has shown that skilled performers display significant losses in prediction capability involving sports-related movement tasks. For example, Abernethy and colleagues have demonstrated that skilled racquet sport players use cues from the arm and racquet region to secure essential information regarding the direction and force of an opposing player's stroke (for a summary of study series see Abernethy, 1991). However, when arm and racquet cues were eliminated from vision, expert performers displayed significant losses in ability to predict direction and force of the opponent's stroke (Abernethy & Russell, 1987a). Without familiar cues accessible to the performer, it appears the process of formulating an accurate percept of the performance situation may be hindered.

It is also important to note that participants were required to report performance estimations according to two different measurement forms. For example, both CA and SP were expressed as an angle in degrees. In contrast, IP was expressed as a distance in inches. When considering that (a) participants were not calibrated to the instrumentation system; and, (b) received no KR from the experimenter at any time, it is possible that participants experienced difficulty transforming raw sensory data into a measurement scale involving an angle (degrees) than a measurement scale employing a distance (inches). Such an interpretation suggests that an individual's level of familiarity with an imposed measurement scale may have profound influence on a performer's ability to report his performance with accuracy. This submission is supported by Newell and Boucher (1974) who found that participants reported performance estimates with less accuracy when asked to express their estimate in inches than participants who reported estimates in millimetres even though no difference in actual movement error was displayed between the two groups.

Since the ability to transform an error signal into a reportable form (subjective reinforcement) is thought to be a learned phenomenon (Schmidt,1975), it is postulated that a calibration period may be required to increase the proficiency with which participants can detect and transform CA and SP error signals into a reportable form when vision of ball trajectory is occluded. Calibrating individuals to a parameter scale involving angles may prove important for strengthening subjective reinforcement for detecting clubface changes in degrees.

In regards to the statistically significant difference found between the LOW and HIGH groups for the IP variable, it is possible that the IP condition allowed participants the opportunity to formulate and verify perceptions utilising more familiar and in this experimental condition, more accessible response-produced feedback cues. For example, when the golf ball was contacted on or very near the "sweetspot" of the club, a very distinct cracking sound was produced. This sound is a source of sensory feedback which the golfer could have used to formulate or verify what he believed to have just occurred. In addition, proprioceptive feedback was also readily accessible for use as a calibration source because golfers were able to feel where the ball had been hit on the clubface through the vibration the impact produced on the club. When considering that participant club speed ranged from 70 to 115 miles/hour, it was almost impossible for participants to actually see the impact location of the ball against the club. Furthermore, shank balls were eliminated from the data set, and occluding ball trajectory from participant vision did not appear to influence perception of performance in the same manner in which performance perceptions for CA and SP appeared to be influenced. Therefore, sensory sources such as proprioception or audition may play a greater role in the detection of IP error than vision. In this study, neither proprioceptive nor auditory sources were occluded; therefore, it is suggested that the LOW group displayed superior performance estimates when compared to the HIGH group because they handled parameter specific sensory information more effectively for the IP variable.

As an additional comment, it should be noted that participants were asked to use their own driver or three wood in this study, and therefore, a wide range of club types were used. This would not be particularly noteworthy except for the fact that clubheads come in a variety of sizes (i.e., standard, mid-size, oversize) and in today's expanding market, a golfer can purchase a club with a bigger "sweetspot". A club with a larger "sweetspot" is intended to minimize the ill effects of a shot that is hit off-centre. One disadvantage to purchasing such a club is that it is said to decrease one's "feel". Therefore, equipment type may influence one's capacity to formulate a performance estimate on the IP variable. Interestingly, it was observed that many of the low handicap participants, especially those with a handicap of six or below, used an old standard wood; whereas, a large portion of the high handicap group possessed and used some of the newest state-of the art clubs with midsize or oversized clubheads. When one low handicapped participant was asked why he still used an old driver with a standard clubhead, his responding comment was that he could feel the impact location of the ball a lot better than he could with some of the new drivers. In this case, a standard clubhead was chosen based on its sensitivity to impact point. Perhaps then, a factor influencing the superior performance estimations by low rather than high handicapped golfers for the IP variable was partly related to the type of equipment used in the study.

CHAPTER SIX

STUDY THREE

Purpose

Study Two was designed to address whether low handicap golfers display superior error detection capabilities as compared to high handicap golfers when asked to estimate their performance on the following three swing attributes: clubface angle (CA), impact point (IP), and clubhead swing path (SP). Study Two findings indicated when: (a) ball trajectory is occluded from participant vision; or when, (b) calibration to the instrumentation system is restricted; scores of performance judgement (AE and E) are not statistically different between low and high handicapped golfers. One leading interpretation of this data suggests that participants experienced difficulty in transforming error signals into the measurement form used in this study for defining parameter scale categories of each clubface aspect. Since the ability to transform an error signal into reportable form (subjective reinforcement) is thought to be learned (Schmidt, 1975), it was postulated that the implementation of a pre-test calibration session may improve the proficiency with which participants detect and transform CA and SP error signals into the required measurement form when vision of ball trajectory is eliminated during a no-KR test session.

Like the previous study, the purpose of Study Three was to address the error detection capabilities of performers regarding the execution of a complex motor skill with one exception. The experimental design of this study was adapted so that participants were provided an opportunity to calibrate their error labeling schemata to the measurement form used by the Pro V system.

Method

All methods were identical to the prior experiment except for the following details.

Participants

Ten low (LOW) handicap golfers (mean handicap = 7), and ten high (HIGH) handicapped golfers (mean handicap = 23) not involved in the previous study, were recruited from an outlying community of a major Canadian city. Mean age of the LOW group was 43 years (range = 24 to 66 years); while, mean age of the HIGH group was 39 years (range = 16 to 54 years). Table 5 presents participant characteristics for this study.

Data Collection Procedure

The experimental session for this study was also divided into three phases: the Familiarization phase, the Testing phase, and a Debriefing phase. The procedure protocol for the Familiarization and the Debriefing phase was identical to Study Two. The distinguishing feature of Study Three was the Testing phase which, is described below (refer to Figure 26 for diagram of experimental session).

Testing Phase. Participants followed the same procedure described in Study Two except participants in this study received a calibration session consisting of ten trials before each test set. Immediately following each swing in the calibration session, the golfer was provided with performance knowledge regarding the parameter that the participant was asked to focus on in the twenty swing no-KR test set which directly succeeded calibration. System measurements were provided verbally to the participant by

Table 9

Participant Characteristics for Study Three

	Participant	Handicap	Age	Years Played*
Low Handicap Group	1	10	61	30-34
	2	2	33	20-24
	3	10	66	30-34
	4	0	24	15-19
	5	8	38	10-15
	6	9	35	5-9
	7	10	51	10-15
	8	9	29	10-14
	9	7	49	10-14
	10	6	42	15-19
Mean		7	43	-
SD		4	14	-
High Handicap Group	11	26	52	10-14
	12	30	54	5-9
	13	20	41	11-15
	14	20	46	11-15
	15	28	22	5-9
	16	20	54	15-19
	17	30	26	1-4
	18	20	16	5-9
	19	20	48	15-19
	20	20	34	5-9
Mean		23	39	-
SD		5	14	-

* Years of golf experience was a self-reported estimate supplied by the participant and is displayed within an approximate category range: 1-4, 5-9, 10-14, 15-19, 20-24, 25-29, and 30-34 years.

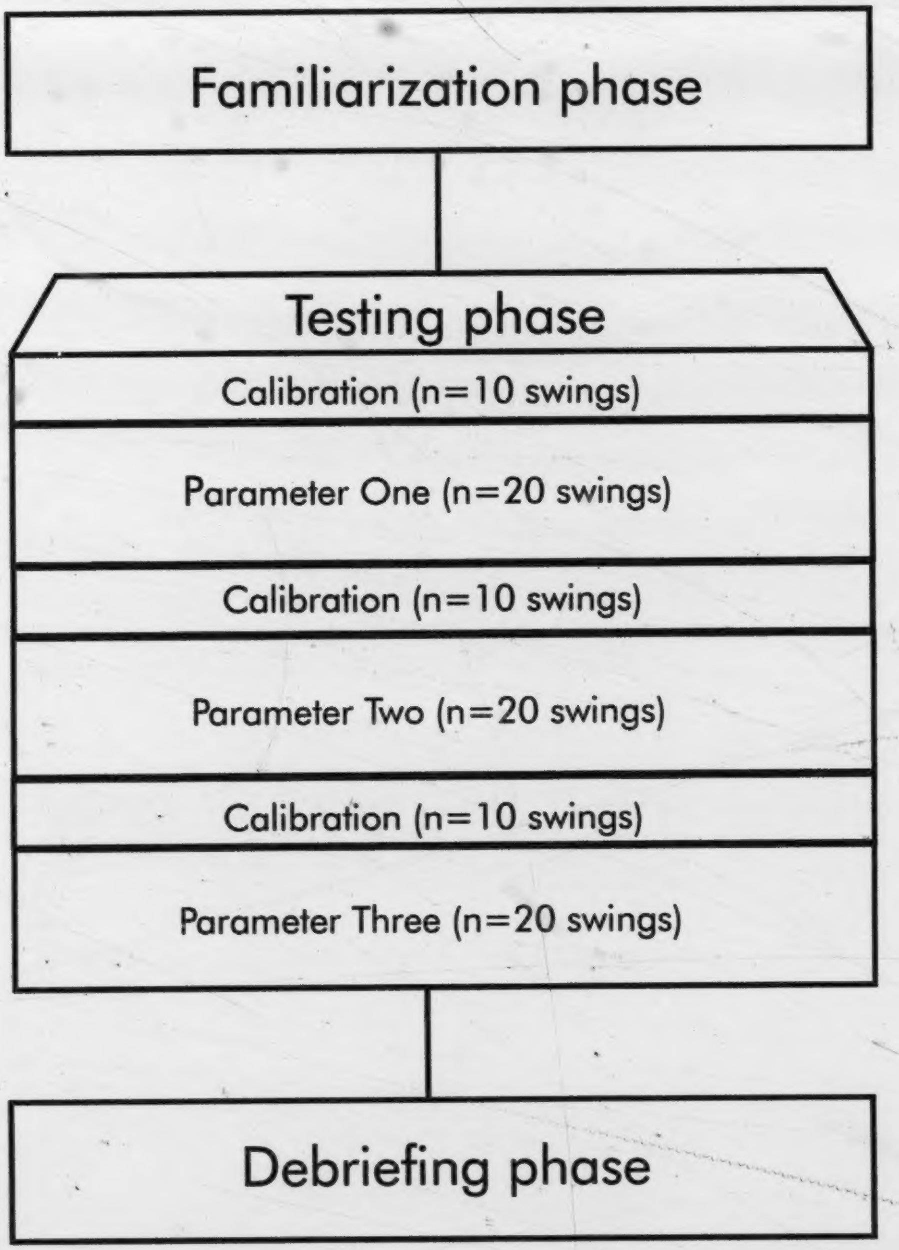
Familiarization phase
Testing phase
Calibration (n=10 swings)
Parameter One (n=20 swings)
Calibration (n=10 swings)
Parameter Two (n=20 swings)
Calibration (n=10 swings)
Parameter Three (n=20 swings)
Debriefing phase

Figure 26. Overview of experimental session for Study Three.

the experimenter. With the inclusion of the calibration set, each golfer executed 90 swings in this testing protocol.

Data analysis

Motor Performance. The data were analysed using the procedure outlined for Study Two. In addition, a chi-square goodness of fit test was used to determine the plausibility of the test-wiseness hypothesis.

Test-wiseness hypothesis. Although the purpose of the calibration set was to accustom golfers to the instrumentation system and measurement report scale utilised in this study, it is possible that the calibration set equipped participants with "test-wise reasoning strategies". Borrowed from the domain of educational assessment, test-wiseness is a term used to denote "an individual's capability to utilize the characteristics of a test and/or test-taking situation to receive an optimal score" (Millman et al., 1965, p. 707). Instead of responding to a test item solely on the basis of an individual's subject matter knowledge, the test-taker employs test-wiseness principles to increase the probability of a correct response (Millman et al., 1965). For example, when answering a multiple choice item on an exam, a test-taker may utilize relevant content information from other test items or options to answer the question. Although test-wiseness principles are independent of the subject matter for which the test item purports to measure, Rogers and Bateson (1991a) suggest that when test-wiseness principles are coupled with partial content knowledge, this is sufficient to increase the probability of correctly responding to items susceptible to test-wiseness. In this study, participants were exposed to ten calibration trials before the no-KR test session. If a participant produces readings with minimal performance variability during calibration (e.g., he hits the ball 0.25" or 0.50" inches on the heel for all ten trials), it is possible that the participant may use this a priori knowledge for making a performance judgement in the no-KR test session. For example, if an individual is informed that he hit the ball 0.25" or 0.50" inches on the heel for all ten trials, it is possible that the participant may use the calibration KR and report 0.25" or 0.50" on the heel of the club during the test session, regardless of what he might perceive his impact point to be. To examine the viability of participant use of test-wiseness for performance judgement, an expected pattern or frequency distribution of motor performance was determined for every participant on each swing dimension for the no-KR test session. For each parameter, expected frequencies for each of the seven possible motor performance categories were determined using the motor response pattern displayed by the participant in the calibration set. A chi-square for goodness of fit was then calculated to determine the degree of divergence between the observed frequency distribution of motor performance obtained in the no-KR test session and the expected pattern of motor response frequencies.

Results

Motor Performance.

Performance Mean and Standard Deviation. Analysis of mean performance error revealed no statistically significant difference between LOW and HIGH groups for CA (mean = 0.85 vs -0.84 deg, respectively), IP (mean = 0.01 vs -0.19 in., respectively), or SP (mean = 0.25 vs -0.10 deg, respectively). Like Study Two, these data indicate that the motor performance of both LOW and HIGH groups were similar for all clubface swing dimensions.

Analysis of mean standard error for CA motor performance revealed a statistically significant difference between the LOW (mean SD = 5.42 deg) and the HIGH (mean SD = 7.55 deg) handicap groups, *t*(18) = -2.98, p <.01. Analysis of the mean standard deviation for SP motor performance also revealed a statistically significant difference between the LOW (mean SD = 2.03 deg) and HIGH (mean SD = 2.76 deg) handicap groups, *t*(18) = -3.05, p <.01. These data indicate that participants in the low handicap group performed with significantly greater consistency on CA and SP swing parameters than the high handicap group. However, analysis of IP motor performance did not yield a statistically significant difference between LOW and HIGH groups. Mean standard deviation for the LOW group was 0.34 in.; while the mean standard deviation for the HIGH group was 0.39 in. Therefore, the LOW group did not perform with significantly greater consistency on the IP dimension than the HIGH group.

The mean and standard deviation values for CA, IP, and SP regarding actual motor performance are displayed in Table 10 for the participant sample.

Chi-square Test for Goodness of Fit. For the low handicapped group, chi-square analyses showed that the observed pattern of motor performance was significantly different than the expected performance distribution for 10%, 40%, and 50% of group participants regarding CA, IP, and SP performance, respectively. For the high handicapped group, chi-square analyses rendered a statistically significant difference between observed and expected motor performance frequency for 20% of group participants regarding both CA and IP performance, and 30% of group participants

Table 10

Participant Mean and Standard Error for Performance of Clubface Angle (CA), Impact Point (IP), and Swing Path (SP), Study Three

	Participant	Clubface Angle (degrees)		Impact Point (inches)		Swing Path (degrees)	
		Mean	SD	Mean	SD	Mean	SD
Low Handicap Group	1	-4.28	5.15	-0.24	0.34	-3.73	3.02
	2	7.50	4.52	0.29	0.37	0.20	1.60
	3	4.90	6.01	0.25	0.37	1.50	1.36
	4	1.55	4.40	0.75	0.27	1.63	1.45
	5	-1.90	8.00	-0.22	0.46	-0.67	1.90
	6	-2.62	4.74	0.00	0.37	1.20	2.63
	7	3.33	5.30	0.12	0.36	-0.20	1.87
	8	-5.12	4.59	-0.01	0.26	0.43	1.84
	9	8.70	6.43	0.13	0.37	2.10	2.48
	10	-3.60	5.00	-0.29	0.22	0.03	2.16
	Mean	**0.85**	**5.42**	**0.01**	**0.34**	**0.25**	**2.03**
High Handicap Group	11	-3.65	8.57	0.43	0.44	-3.40	2.37
	12	-1.73	8.52	-0.45	0.10	-3.27	3.33
	13	0.82	6.33	-0.45	0.33	-1.43	2.83
	14	-2.85	7.85	-0.28	0.46	-0.60	2.8[illegible]
	15	1.42	4.90	-0.32	0.38	1.78	2.85
	16	-0.52	9.04	0.53	0.53	7.90	2.31
	17	5.37	11.42	0.16	0.54	1.53	2.66
	18	5.00	7.22	-0.20	0.41	6.17	3.38
	19	-6.78	6.40	-0.58	0.27	-2.57	3.25
	20	-5.50	5.22	0.07	0.40	-7.13	1.70
	Mean	**-0.84**	**7.55**	**-0.10**	**0.39**	**-0.10**	**2.76**

regarding SP performance. Consequently, it appears that for the majority of participants, the test-wiseness hypothesis cannot be ruled out since the frequency distributions obtained during the calibration phase have the same shape as those obtained during the performance phase. Participant chi-square values for CA, IP, and SP are displayed in Table 11.

A sample of performance scores for all three parameters (CA, IP, and SP) are presented in Figures 1-6 (Appendix D).

Table 11

Participant Chi Square Values for Clubface Angle (CA), Impact Point (IP), and Swing Path (SP)

	Participant	Clubface Angle (CA)	Impact Point (IP)	Swing Path (SP)
Low Handicap Group	1	7.92	3.67	6.50
	2	9.75	1.00	13.50
	3	10.29	15.29	8.63
	4	12.13	46.25	0.50
	5	38.25	5.42	1.25
	6	8.85	13.00	14.38
	7	6.17	5.38	2.25
	8	3.13	16.63	7.50
	9	1.13	23.27	17.13
	10	8.25	9.33	39.13
	Mean	**10.59**	**13.92**	**11.08**
High Handicap Group	11	7.92	3.27	14.38
	12	0.85	7.56	11.42
	13	5.67	3.10	5.00
	14	2.67	13.83	4.27
	15	9.25	9.50	2.20
	16	3.67	8.10	0.00
	17	21.58	9.65	7.10
	18	2.17	3.58	0.50
	19	6.07	4.60	6.60
	20	20.75	13.00	80.00
	Mean	**8.06**	**7.62**	**14.59**

Note : Cutoff chi-square value for .05 level of significance (*df* = 6) is 12.59.

Judgements of Performance Error.

Absolute error (AE). Analysis of the CA data revealed a statistically significant difference between LOW (mean AE = 1.05 deg) and HIGH (mean AE = 1.39 deg) handicap groups with regards to absolute error, $t(18) = -2.10$, $p < .05$. A statistically significant difference was also exhibited between the LOW (mean AE = 0.78 in.) and HIGH (mean AE = 1.41 in.) handicap groups for the IP variable, $t(18) = -3.89$, $p < .01$. Finally, analysis of the SP data revealed a statistically significant difference between LOW (mean AE = 0.83 deg) and HIGH (mean AE = 1.54 deg) handicap groups for absolute error, $t(18) = -4.98$, $p < .001$. These results, visually displayed in Figure 27, 28, and 29, respectively, suggest that participants in the LOW group displayed superior judgements of movement production accuracy when compared to HIGH participants for CA, IP, and SP.

A summary of mean absolute error (AE) values for each participant in the study may be found in Table 12.

Total Variability (E). A statistically significant difference was found in CA between LOW and HIGH for E scores (mean E = 1.39 vs.1.87 deg, respectively), $t(18) = -2.57$, $p < .05$. Analysis of the IP data revealed that LOW, in comparison to HIGH, also displayed statistically significant lower E scores (mean E = 1.09 vs.1.75 in., respectively), $t(18) = -3.94$, $p < .001$. And finally, analysis of the SP data revealed a statistically significant difference between the LOW (mean E = 1.16 deg) and the HIGH (mean E = 1.96 deg) for total variability, $t(18) = -4.61$, $p < .001$. These results are visually presented in Figures 30, 31, and 32, respectively, and reveal that participants in the LOW group

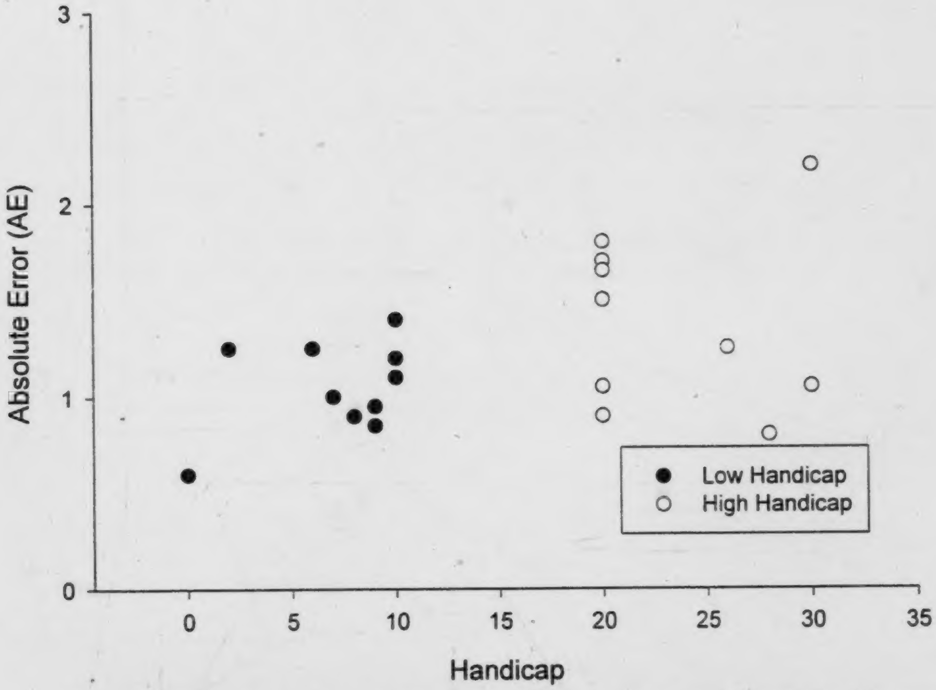

Figure 27. Mean absolute error (AE) for performance judgement of clubface angle (CA) as a function of participant handicap, Study Three.

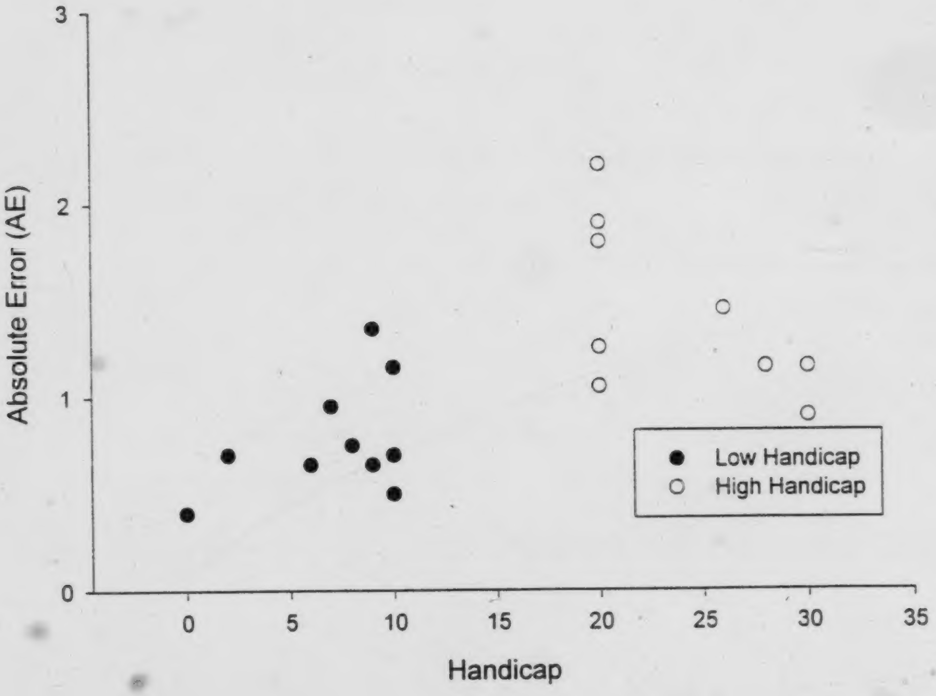

Figure 28. Mean absolute error (AE) for performance judgement of impact point (IP) as a function of participant handicap, Study Three.

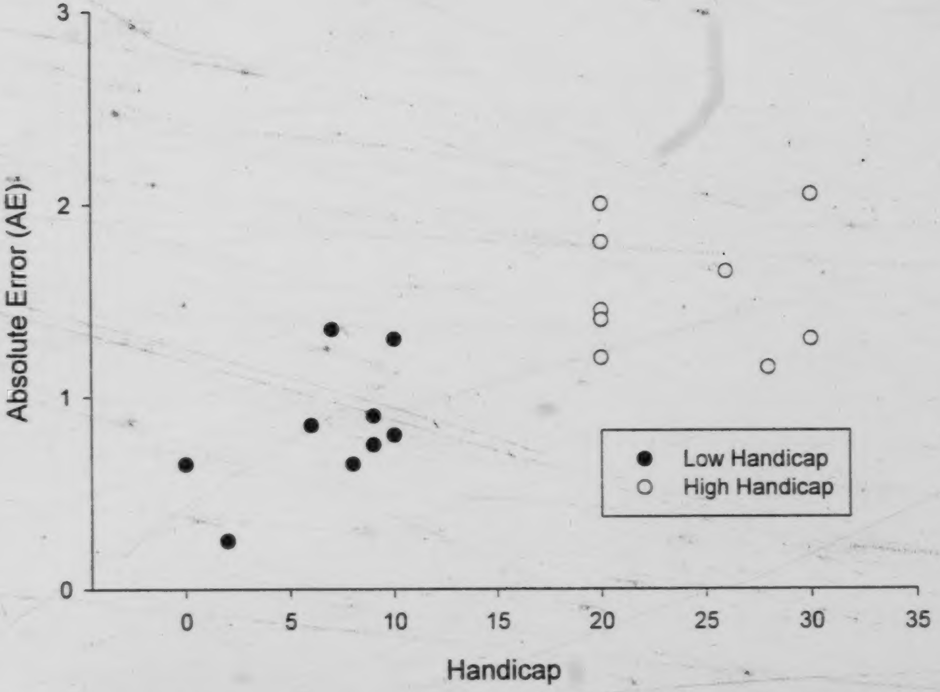

Figure 29. Mean absolute error (AE) for performance judgement of clubhead swing path (SP) as a function of participant handicap, Study Three.

Table 12

Mean Absolute Error (AE) for Performance Judgement of Clubface Angle (CA), Impact Point (IP), and Swing Path (SP), Study Three

	Participant	Clubface Angle (CA)	Impact Point (IP)	Swing Path (SP)
Low Handicap Group	1	1.10	1.15	1.30
	2	1.25	0.70	0.25
	3	1.20	0.70	0.80
	4	0.60	0.40	0.65
	5	0.90	0.75	0.65
	6	0.85	1.35	0.90
	7	1.40	0.50	0.80
	8	0.95	0.65	0.75
	9	1.00	0.95	1.35
	10	1.25	0.65	0.85
Mean		**1.05**	**0.78**	**0.83**
SD		**0.24**	**0.29**	**0.32**
High Handicap Group	11	1.25	1.45	1.65
	12	2.20	1.15	2.05
	13	1.05	2.20	1.40
	14	1.50	1.25	1.20
	15	0.80	1.15	1.15
	16	1.70	1.90	1.45
	17	1.05	0.90	1.30
	18	0.90	1.05	1.80
	19	1.65	1.80	1.40
	20	1.80	1.25	2.00
Mean		**1.39**	**1.41**	**1.54**
SD		**0.45**	**0.42**	**0.32**

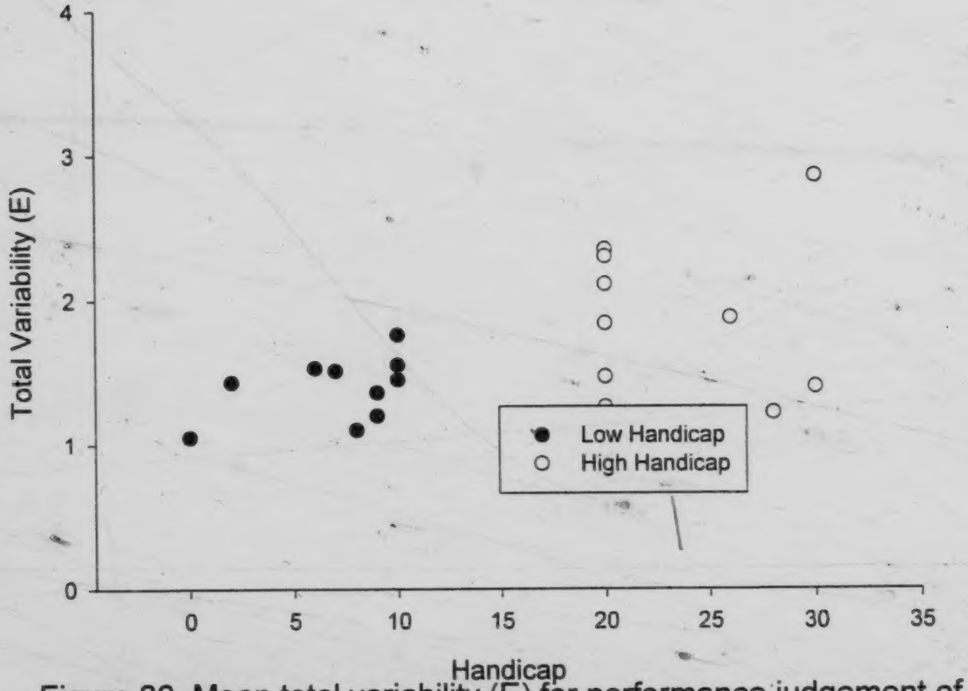

Figure 30. Mean total variability (E) for performance judgement of clubface angle (CA) as a function of participant handicap, Study Three.

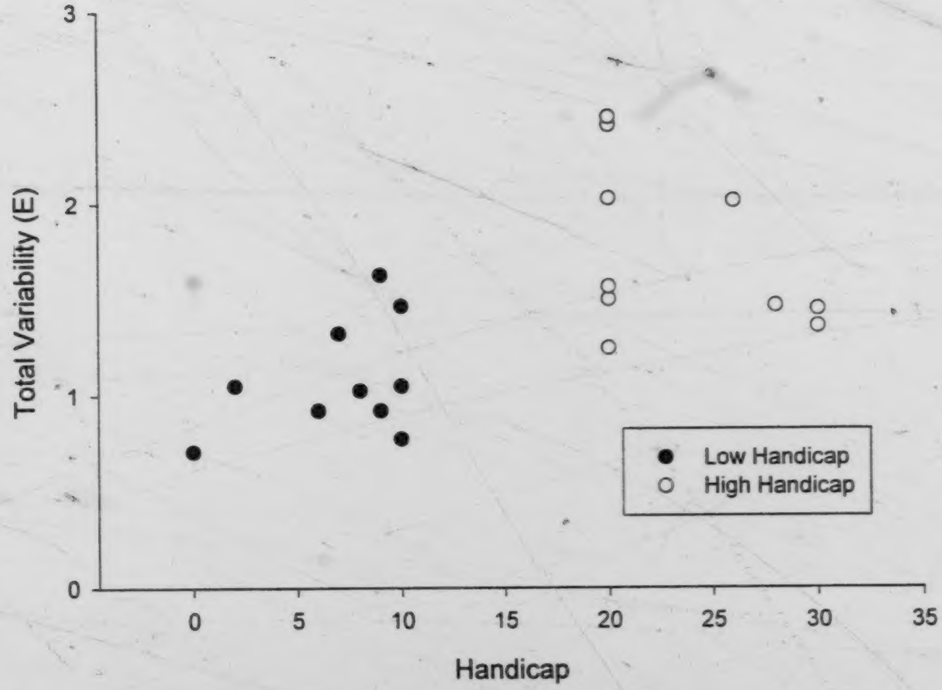

Figure 31. Mean total variability (E) for peformance judgement of impact point (IP) as a function of participant handicap, Study Three.

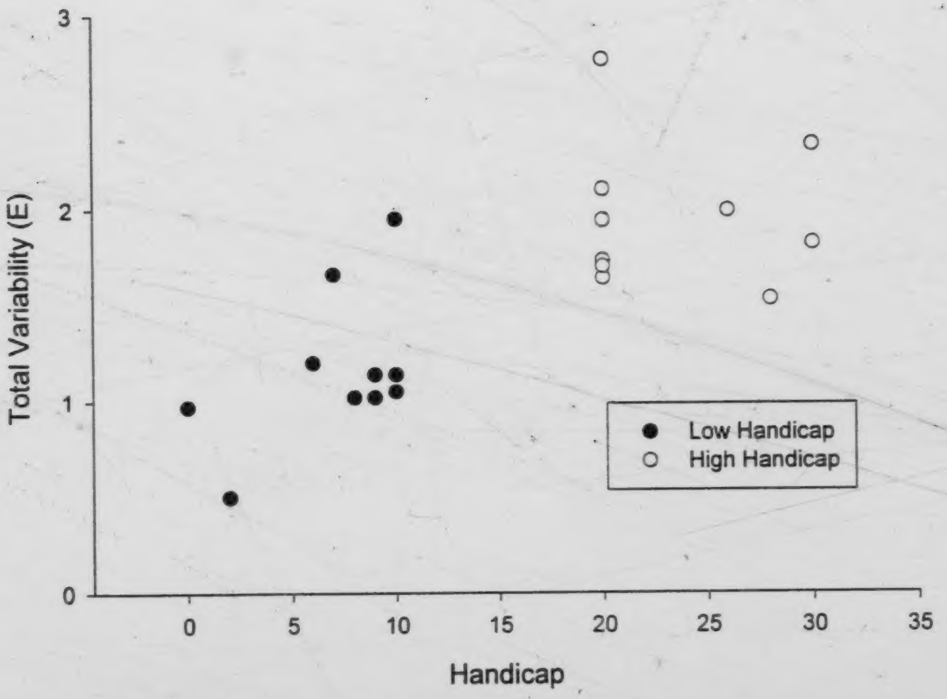

Figure 32. Mean total variability (E) for performance judgement of clubhead swing path (SP) as a function of participant handicap, Study Three.

exhibited greater error detection capabilities than the HIGH group for all clubface parameters: CA, IP, and SP.

A summary table presenting total variability (E) values for each participant is displayed in Table 13.

Table 13

Mean Total Variability (E) for Performance Estimation of Clubface Angle (CA), Impact Point (IP), and Swing Path (SP), Study Three

	Participant	Clubface Angle (CA)	Impact Point (IP)	Swing Path (SP)
Low Handicap Group	1	1.45	1.47	1.95
	2	1.43	1.05	0.50
	3	1.55	1.05	1.05
	4	1.05	0.71	0.97
	5	1.10	1.02	1.02
	6	1.20	1.63	1.14
	7	1.76	0.77	1.14
	8	1.36	0.92	1.02
	9	1.52	1.32	1.66
	10	1.53	0.92	1.20
	Mean	**1.39**	**1.09**	**1.16**
	SD	**0.22**	**0.30**	**0.39**
High Handicap Group	11	1.88	2.01	1.99
	12	2.86	1.36	2.33
	13	1.47	2.41	1.73
	14	1.84	1.50	1.64
	15	1.22	1.47	1.53
	16	2.35	2.45	1.94
	17	1.40	1.45	1.82
	18	1.26	1.24	2.10
	19	2.11	2.02	1.70
	20	2.30	1.57	2.77
	Mean	**1.87**	**1.75**	**1.96**
	SD	**0.54**	**0.44**	**0.37**

Discussion

In the previous study, it was postulated that the implementation of a pre-test calibration session may improve the proficiency with which participants detect and transform error signals on parameters where primary sensory feedback or augmented information is suspended. The primary objective in conducting this study was to examine judgements of movement production accuracy (error detection) between low and high handicapped golfers after exposure to a calibration session.

The results of the present experiment demonstrate that low handicapped golfers display superior judgements of performance on all clubface dimensions (CA, IP, and SP) when compared to high handicapped golfers (Figures 27 - 32). With respect to IP, the LOW group displayed less absolute error and total variability in performance judgement than the HIGH group in both Studies Two and Three. In fact, this finding was exhibited in Study Three even though the LOW and HIGH groups performed with similar motor performance consistency on the IP swing dimension. This finding strongly indicates that the low handicapped golfers may have utilized an acquired cognitive mechanism to detect and perceive changes in performance with greater accuracy than the high handicapped golfers. However, this is not to say that high handicapped golfers did not also possess a mechanism for the detection of error. Rather, it is proposed that the low handicapped golfers displayed a stronger, more efficient mechanism to detect and compare changes in performance against an internal standard of reference than the mechanism possessed by the high handicapped golfers.

Data presented in Study Two revealed that low handicapped golfers did not display superior performance judgements for CA and SP clubface parameters when compared to high handicapped golfers. A leading interpretation of these data suggested that flight trajectory may be a primary strategy with which performers use to obtain reliable CA and SP information for the evaluation of motor performance. When flight trajectory of the ball is occluded from participant vision, it is possible that a primary source of response-produced feedback becomes inaccessible to the performer. As such, the performer may experience difficulty comparing actual response feedback against his acquired internal standard of reference. Consequently, an inaccurate percept of CA and SP swing performance is formulated by the performer. However, findings revealed in this study suggest when low handicapped golfers are provided an opportunity to calibrate their error labeling schemata to the measurement form employed in the study, they display superior performance judgement accuracy in comparison to high handicapped golfers for CA and SP. Most importantly, this finding occurred even though high handicapped golfers were also exposed to the ten swing calibration set and flight trajectory was occluded from participant vision. Once calibrated to the measurement scale, this data suggests that low handicapped participants were better able to utilize a feedback source(s), other than vision, to obtain information for the formulation of performance judgements regarding CA and SP parameters. Moreover, these findings support the notion that the detection and accurate interpretation of an error signal during the execution of a task may be relatively specific to the feedback condition under which practice occurs. In essence, the calibration session provides participants an opportunity to *practice* detecting and transforming error signals into the required measurement form.

As previously stated, the purpose of the calibration set was to accustom golfers to the instrumentation system and measurement report scale utilized in this study. However, one consideration still to be examined for study interpretation is the test-wiseness hypothesis. If, for example, an individual produces a swing path system reading of "2°, 4°, or 0°" for all ten calibration trials, his distribution of motor performance readings displays little variability. As a result of minimal performance variability during calibration, it is possible that such a participant might glean "test-wiseness reasoning strategies" to formulate a performance judgement rather than basing performance judgements on actual perceptions of swing performance in the no-KR test set. Analysis of the mean standard deviation of motor performance revealed that the LOW group performed with significantly greater consistently for CA and SP swing attributes than the HIGH group. Such a finding suggests that exposure to too many calibration trials may equip the skilled performer with test-wiseness. However, upon further examination, chi-square analyses showed that the HIGH group, rather than the LOW group, generally exhibited motor performance characteristics that could be expected on the basis of their motor performance during the calibration phase. Such findings tend to suggest that a higher proportion of participants in the LOW group were not exclusively relying on a priori knowledge to formulate their judgements. It must, however, be noted that for the majority of participants, the test-wiseness hypothesis could not be ruled out. Clarification of this issue awaits further study.

CHAPTER SEVEN

STUDIES TWO AND THREE : GENERAL DISCUSSION AND FUTURE RECOMMENDATIONS

General Discussion

If skilled performers possess a greater capability for detecting their own errors when compared to novice performers, then individuals possessing superior skill should exhibit a greater correspondence between what they perceive to be occurring and the empirical reality of what is actually occurring. Taken together, the results of Studies Two and Three lend support for this statement by providing empirical evidence that indicates low handicapped golfers judge their motor performance on clubface aspects of the golf swing with greater accuracy than high handicapped golfers.

With regards to the IP variable, findings revealed that low, rather than high handicapped golfers, display less absolute error and total variability in performance estimation scores for both Studies Two and Three. In terms of CA and SP swing factors, the LOW group displayed less error in AE and E performance estimation scores than the HIGH group when the experimental design was adapted to include a ten swing pre-test calibration set (Study Three).

Considering that no significant difference was displayed between the LOW and HIGH groups for mean and mean standard deviation of motor performance, the low handicapped group displayed greater accuracy in performance judgement when compared to the high handicap group for IP in Study Two and CA, IP, and SP in Study Three. This provides strong support for the notion that low handicapped golfers possess a greater capacity to detect and perceive changes in performance with greater accuracy than the high handicapped golfers. Furthermore, support for this notion was strengthened in Study Three, when low handicapped golfers were provided an opportunity to calibrate their error labeling schemata to the measurement form employed in this project. Findings revealed that the low handicap golfers displayed superior performance judgement accuracy for CA and SP when compared to high handicapped golfers, who were also exposed to pre-test calibration. It appears that superior error detection capability was displayed after the LOW group was provided an opportunity to practice detecting and transforming error signals into the format required by the instrumentation system.

In addition, interpretation of the above findings brings to light several important points for future discussion involving motor expertise and the execution of complex motor tasks. First, attention should be directed towards dialogue highlighting the relationship between motor skill complexity and error detection. As it has been previously defined, a complex motor skill involves the physical action of both gross and fine musculature for the successful execution and smooth co-ordination of a significant number of parts or components to achieve a task goal. As such, each component that comprises a complex motor skill serves a function distinct from one another. When discussing clubface aspects of the golf swing, the IP swing variable was said to be distinct from CA and SP swing factors in that IP is responsible for the distance a ball travels. In contrast, CA and SP are clubface aspects that interact to dictate the direction (flight trajectory) of a golf shot. Since we possess a limited processing capacity, it is possible that performers discriminate between sensory sources and utilize the source that elicits the most appropriate or reliable information for detecting the occurrence of a performance error regarding a component of a complex motor skill. Such a suggestion implies that response-produced feedback may be weighted, sought after, and utilized in accordance to its reliability (Howarth, 1978). Moreover, the detection and accurate interpretation of performance error regarding different components of a complex motor skill may depend on various sensory sources for information. For example, study findings indicate that sensory sources such as proprioception and audition may play a greater role in the detection of IP performance error than the use of vision for the detection of error. In contrast, vision may play a greater role in the detection of SP and CA performance error than the use of proprioception and audition.

Second, when a primary source of sensory information is eliminated, the performer may experience difficulty comparing actual response feedback against expected sensory consequences. As such, error signals are not as readily detected or converted into a reportable form (subjective reinforcement). This suggestion supports the notion that an individual's capability to detect performance error may be relatively specific to the feedback condition under which practice occurs. As learning progresses from the initial stages of skill acquisition towards a level of motor expertise, information regarding response-produced feedback is integrated into a sensorimotor representation by the performer, specific to the learned task. The more practice one has utilizing a particular feedback source, the more important that feedback source becomes in the detection of error and ultimately for the control of movement. That is, if a golfer predominantly uses vision of ball flight trajectory to detect movement errors in CA and SP swing attributes, the more important vision becomes as a response-produced feedback source for the detection and correction of swing errors. When flight trajectory of the ball is occluded from participant vision, a primary source of response-produced feedback becomes inaccessible for the detection of CA and SP errors. Without an adequate period of practice utilizing the less familiar feedback source, a performer may experience difficulty comparing actual response feedback against his internal reference standard. However, study findings suggest that when a performer has been exposed to practice trials (calibration), an improved accuracy in CA and SP performance estimations occur.

Emergent Methodological Concerns and Recommendations for Future Study

In an attempt to assemble a large array of evidence regarding the role motor expertise plays in the detection of error for a complex motor skill, it is necessary to put forth conclusions based on study replication across people and methods. However, utilising a complex motor activity while examining a participant's perception of performance carries with it an array of methodological obstacles. In many respects, this project served an exploratory function with which methods and procedures could be tested and evaluated to determine their value for future research application.

Although the low handicap group was considered to be more skilled than the high handicap group, possessing a handicap of 10 did not make one an "expert". In fact, it was observed by the experimenter that the sample included individuals at an eight or 10 handicap who exhibited swing attributes characteristic of a high handicapped golfer. For example, one individual possessed an eight handicap, yet consistently exhibited a large (i.e., -8°, -12°) outside-to in swing path (see Figure 7, Appendix C). This implies that the upper boundary for the low handicap group may have been set on the high side. To obtain a sample that best represents individuals who possess a consistent record of excellence in the golf domain, it is recommended that the participant sample be delimited to those individuals maintaining a pro status or those who are scratch golfers. However, such a recommendation is accompanied by a word of caution. For this study, the author encountered difficulty recruiting golfers for study participation and ultimately, had to carry out data collection in two different locations to obtain the minimal number of participants. Therefore, it is speculated that delimiting the inclusion criteria for the low handicap group to only those individuals at a scratch handicap level, may extend the amount of time required for participant recruitment and data collection.

When initially choosing the club to be used for the project task, the issue of fatigue was a primary concern. Considering a driver is the longest hitting wood club, it was thought that fatigue may exhibit the greatest influence on participants when using the driver. In an attempt to combat this problem, it was the experimenter's intent to use a five-iron which possesses a lighter, shorter shaft and has a small metal blade with which to impact the ball. Unfortunately, the five-iron could not be employed as the hitting implement of choice since the GolfTek Pro V Swing Analyser™ rendered invalid and unreliable measurements for this club during instrument assessment procedures (see Chapter 4). As such, participants were required to use a driver or three wood in Studies Two and Three. As it was originally speculated, a number of players displayed signs of fatigue during the data collection procedure when they chose to hit the ball with their driver, especially when the testing protocol called for 90 swings. Although participants were given a rest and refreshment break between each parameter set, there were still players in both the LOW and HIGH groups who needed to take a break during the parameter set. One key question that is left unanswered then, is “whether fatigue affected each group in an equivalent manner or differentially?”. For future studies, it is recommended that the issue of physical fatigue be examined more closely and precautionary steps be employed within study methodology to negate the influence that fatigue may have on the formulation of a participant’s performance estimates. For example, the number of swings per trial set may be decreased as well as the number of swings per calibration session; or perhaps, three variables were too many factors to examine in one testing session and variable number should be reduced or at the very least, spread over two testing sessions in the future. Another alternative would be to employ the use of a different instrumentation system which allows for the use of lighter, less physically taxing, clubs.

In Study Two it was found that the LOW group did not exhibit less absolute error or total variability than the HIGH group for CA and SP performance estimation. Considering that CA and SP interact to dictate direction of the shot, one leading interpretation of these findings was that viewing a ball’s flight trajectory might be a primary strategy which performers use to detect movement errors in CA and SP. When flight trajectory is occluded from participant vision, a primary source of response-produced feedback for formulating CA/SP performance estimation is unavailable and accuracy in estimation deteriorates. As such, it is recommended that the error detection capabilities of golfers be examined for CA and SP without a calibration set when participant vision of flight trajectory and ball impact location on the net is not occluded.

In this study, each clubface parameter was isolated and the golfer was asked to focus on one aspect for each variable set. Although the LOW group demonstrated superior judgements of movement production accuracy than the HIGH group for IP (Study Two) and CA, IP, and SP (Study Three), participants were never asked to report on all parameters at once. As an individual is faced with a larger number of stimuli and response options, error signals may become more difficult for the performer to detect. For example, participants display the tendency to underestimate their error on bimanual aiming tasks when asked to focus on both limbs (Sherwood, 1998). Therefore, it is recommended that future studies increase the complexity of the task by asking low and high handicap participants to focus on all three clubface parameters.

Furthermore, during the testing session, an interesting observation was made with regards to focussing on one clubface aspect per trial set and high handicapped participants. On repeated occasions, performance estimates of the HIGH participants appeared to be adversely influenced by a clubface aspect which was not the parameter of focus for the set. For example, on the first swing of a CA set, a participant reports CA to be largely closed. For this swing, the computer reads closed 12°, a large CA deviation, and IP and SP are recorded respectively as Toe 0.50" (Moderate deviation) and Outside-in 4° (Moderate deviation). In this case, the participant's perception of CA is correct. On the next swing, the participant reports a square clubface; whereas, the computer reveals the CA parameter to once again be closed 12° (Large deviation), and SP to once again be Outside-in 4° (Moderate deviation). However, for this swing the IP variable is reported as a centre hit. These results indicate that the change in performance occurred in the IP variable, and not in CA features, as the participant reported. Although the participant's perception of CA is incorrect, such an observation implies that the participant has detected a change in performance but his perception of the source of error is incorrect. As such, it is recommended that parameter interaction be examined in detail to determine its effect on error detection capabilities of skilled and less skilled performers.

Finally, since this study was delimited to male participants, it is recommended that further investigations should also look at the error detection capabilities of skilled and less skilled female golfers.

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APPENDIX A

COVER LETTER AND INFORMED CONSENT FORM

University of Alberta
Faculty of Physical Education and Recreation

May 1, 1998

Dear Sir:

I am presently conducting a research study for partial fulfilment of a Master of Science Degree that investigates the error detection capabilities of golfers. In this study, participants will be asked to hit a series of golf balls (60 or 90 balls) with a driver or three wood focussing on certain aspects of their swing. Participants will either be asked to (a) verbally report their performance on the aspect(s) of focus; or (b) determine the validity of information presented to them by the experimenter regarding the aspect(s) of focus.

At this time, I am looking for golfers with a handicap of 10 and below or a handicap between 20 and 30 to participate in the study. If you fall into one of these two categories, I hope I can have the opportunity to work with you on this project.

The GolfTek ProV Swing Analyzer, an indoor golfing system, will be used to obtain measurements of participant swings. Therefore, a golf cage has been set-up at the University of Alberta. One session will be conducted for this study, lasting approximately 1 to 1½ hours, and will take place at the Patricia Austin Centre (GB-06 Education South), in the basement of the white education building (corner of 114 Street and 87 Avenue). Convenient parking at the University is available for those who participate in the study.

Participants will not receive any pay for participating in the study. However, each participant will receive a computer print-out outlining his swing profile from the GolfTek Pro V Swing Analyzer. Each participant is asked to bring his own golf club (driver or three wood) to use in the study.

Participant data will be used for thesis and research publication purposes. To ensure confidentiality, each individual will be assigned a participant number and all data will be retained in a locked filing cabinet. Data will remain in my possession for a minimum of five years after publication of the research.

This study has been approved by the Ethics Committee of the Faculty of Physical Education and Recreation at the University of Alberta. Participants will not be subjected

◆ *E401 Van Vliet Physical Education and Recreation Centre* ◆ *Edmonton, Alberta, Canada* ◆ *T6G 2H9*
◆
Ph. (403) 492-3566 ◆ *Fax: (403) 492-2364*

to any risk of psychological harm as a direct result of participating in this study. Further, the risk of physical injury will be equivalent to what you normally encounter while hitting golf balls off a tee at a driving range. Should you agree to participate, you will have the option of withdrawing from the study at any time without consequences. If you have any questions or concerns about this project, please do not hesitate to contact me at 433-7113 or my advisor, Dr. Marcel Bouffard at 492-3566. If you agree to participate, appointments can be arranged through me at the aforementioned number and will be scheduled for a time that is mutually convenient (i.e., a morning, afternoon, evening, or week-end).

Thank you for your time and consideration.

Sincerely yours,

Shannon S. D. Bredin

CONSENT FORM

TITLE : The Role of Expertise in the Detection of Error for a Complex Skill

INVESTIGATOR : Shannon Bredin, 542-4500 (Drayton Valley) / 433-7113 (Edmonton)
SUPERVISOR : Dr. Marcel Bouffard, 492-3566

I, ____________________ (please print your name) agree to participate in a research project directed by the above named investigator studying *the error detection capabilities of golfers*. In so doing, I understand fully all of the following statements:

1. The study will consist of one session lasting approximately 45 minutes to 1½ hours. In this session, I will be required to hit 60 or 90 golf balls with my driver or three wood into a mesh cage. I will not be subjected to any risk of psychological harm as a direct result of participating in this study. Further, the risk of physical injury will be equivalent to what I normally encounter while hitting golf balls off a tee at a driving range.
2. I acknowledge that neither the investigator or the University of Alberta will be held responsible for any damage to personal golf equipment as a result of participating in this activity.
3. I understand that I am a volunteer and will not receive any pay during the conduct of this study. Further, I have the option of withdrawing from the study at any time without reason and without prejudice or consequence.
4. Measurements of each swing will be obtained from a GolfTek Pro V Swing Analyzer. At the end of the testing session, I will receive a computer print-out displaying the measurements for every swing executed in the study.
5. I understand that the data collected will be used for thesis and research publication purposes. To ensure confidentiality, I will be identified by a participant number and all data will be retained in a locked filing cabinet by the investigator for a minimum of five years after publication of the research.
6. I have been given the opportunity to ask questions related to this project and these questions have been answered fully and to my satisfaction. If I have any other questions or concerns about this project, I can contact the investigator at the aforementioned number.
7. I have received a copy of this informed consent form.

____________________	____________________
(Name - PLEASE PRINT)	(Name of Investigator - PLEASE PRINT)
____________________	____________________
(Signature)	(Signature of Investigator)
____________________	
(Date)	

APPENDIX B

SAMPLE OF PARAMETER SCALE DIAGRAMS FOR TEST INSTRUCTIONS

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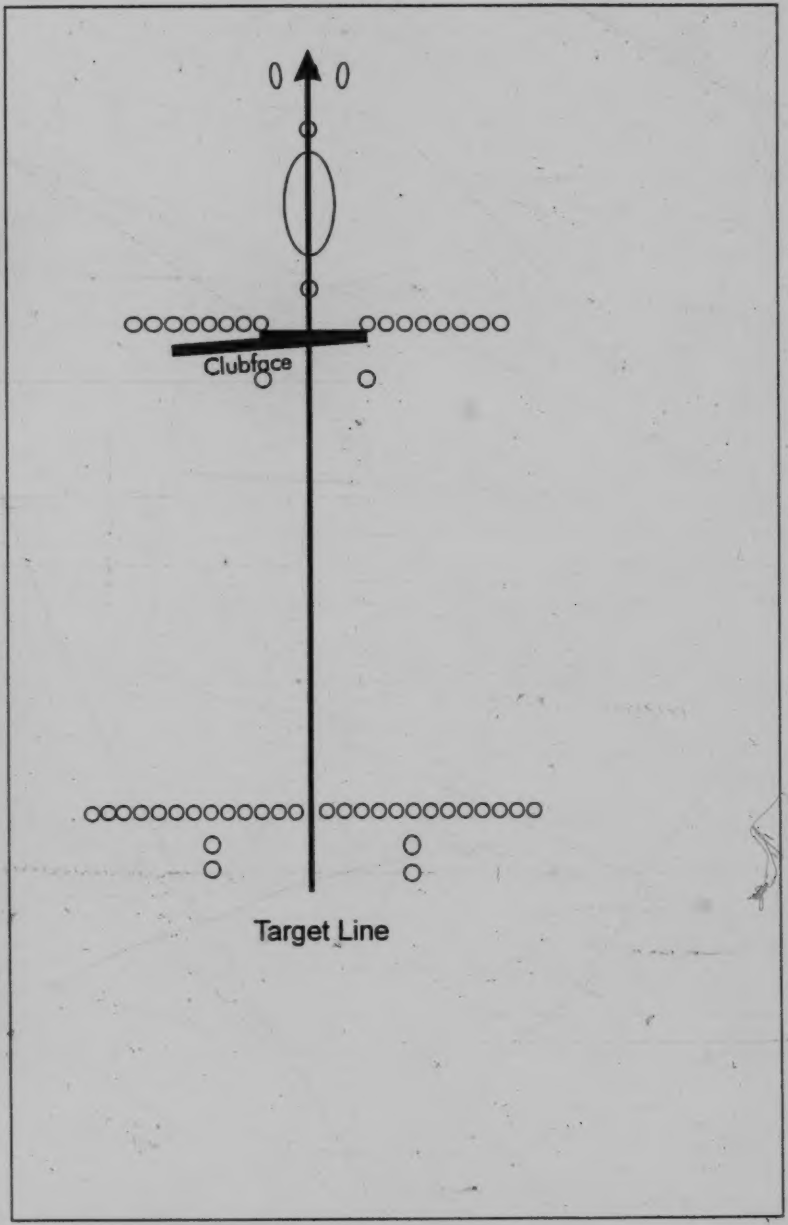
Deviation: Slight


0
0
Clubface
Target Line

Clubface Closed 1- 4°

Figure 1. Illustration depicting a slightly closed clubface (-1° to -4°).

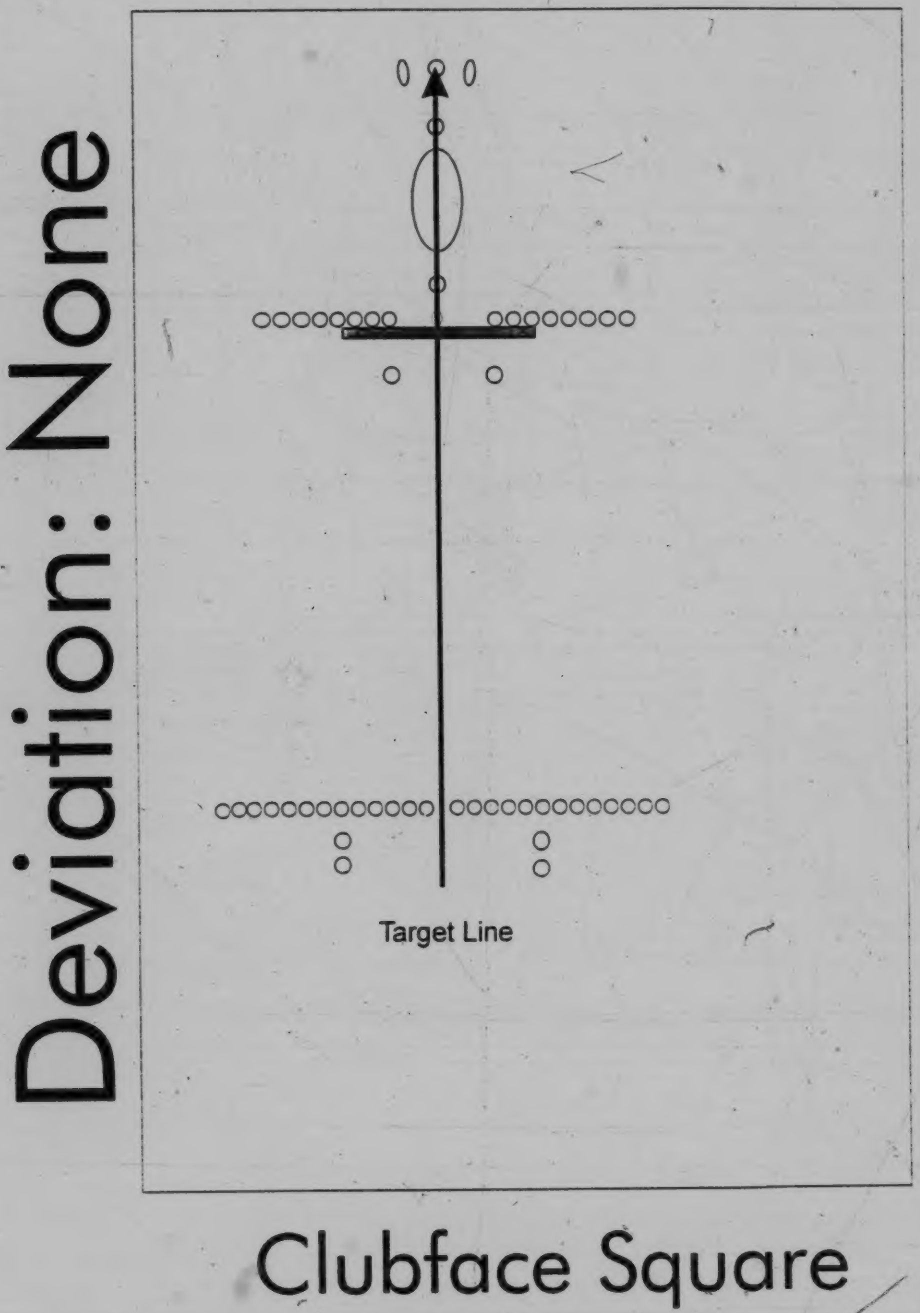
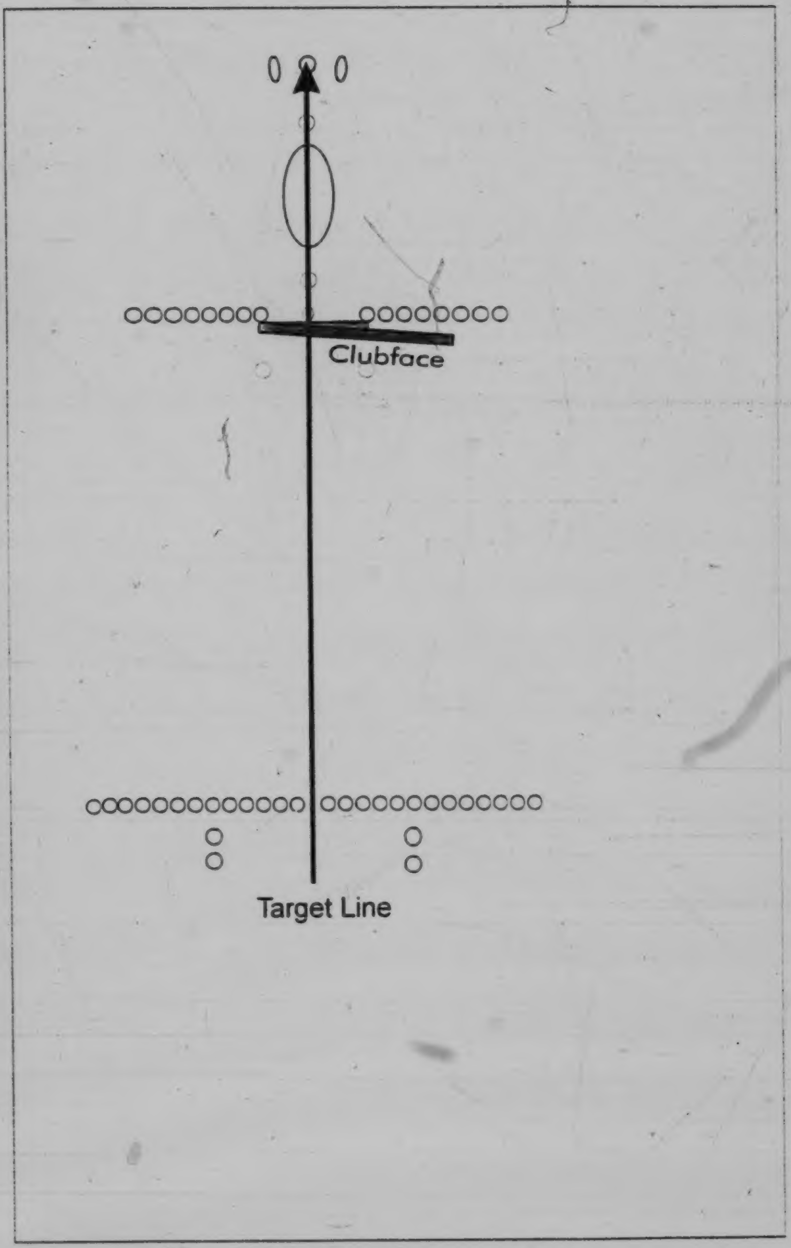

Deviation: None
Target Line
Clubface Square

Figure 2. Illustration depicting a square clubface (0°).

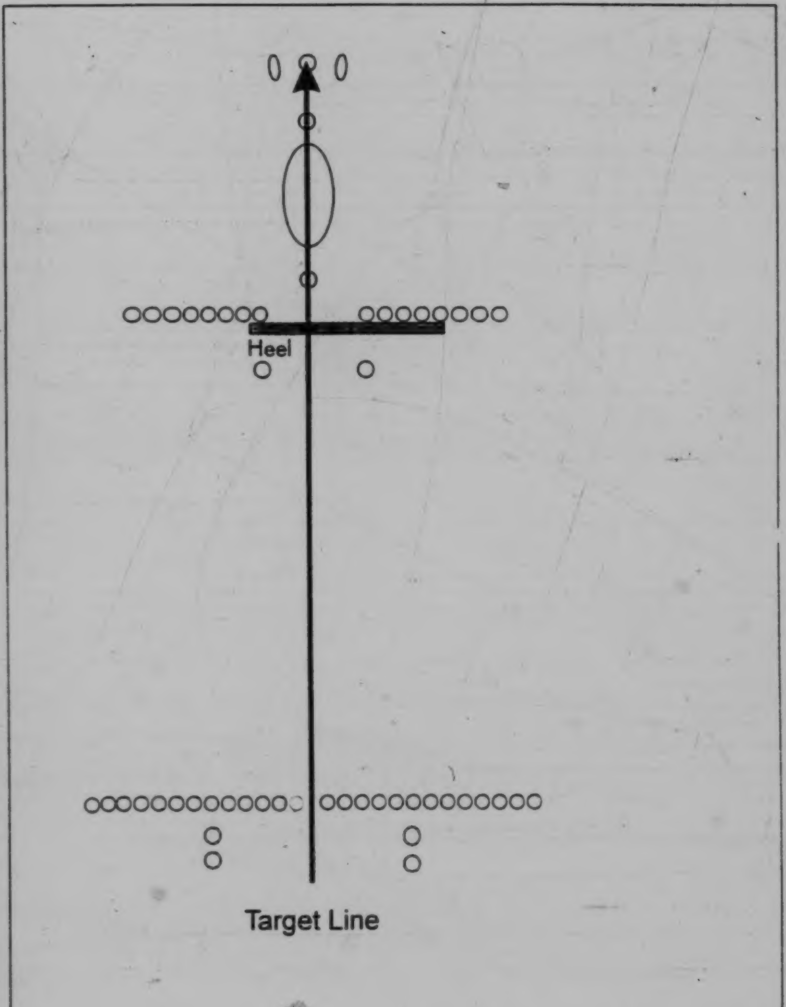
Deviation: Slight


Clubface
Target Line

Clubface Open 1- 4°

Figure 3. Illustration depicting a slightly open clubface (1° to 4°).

Deviation: Moderate


Heel
Target Line

Impact Heel 0.50″

Figure 4. Illustration depicting a moderate heel impact (-O.50″).

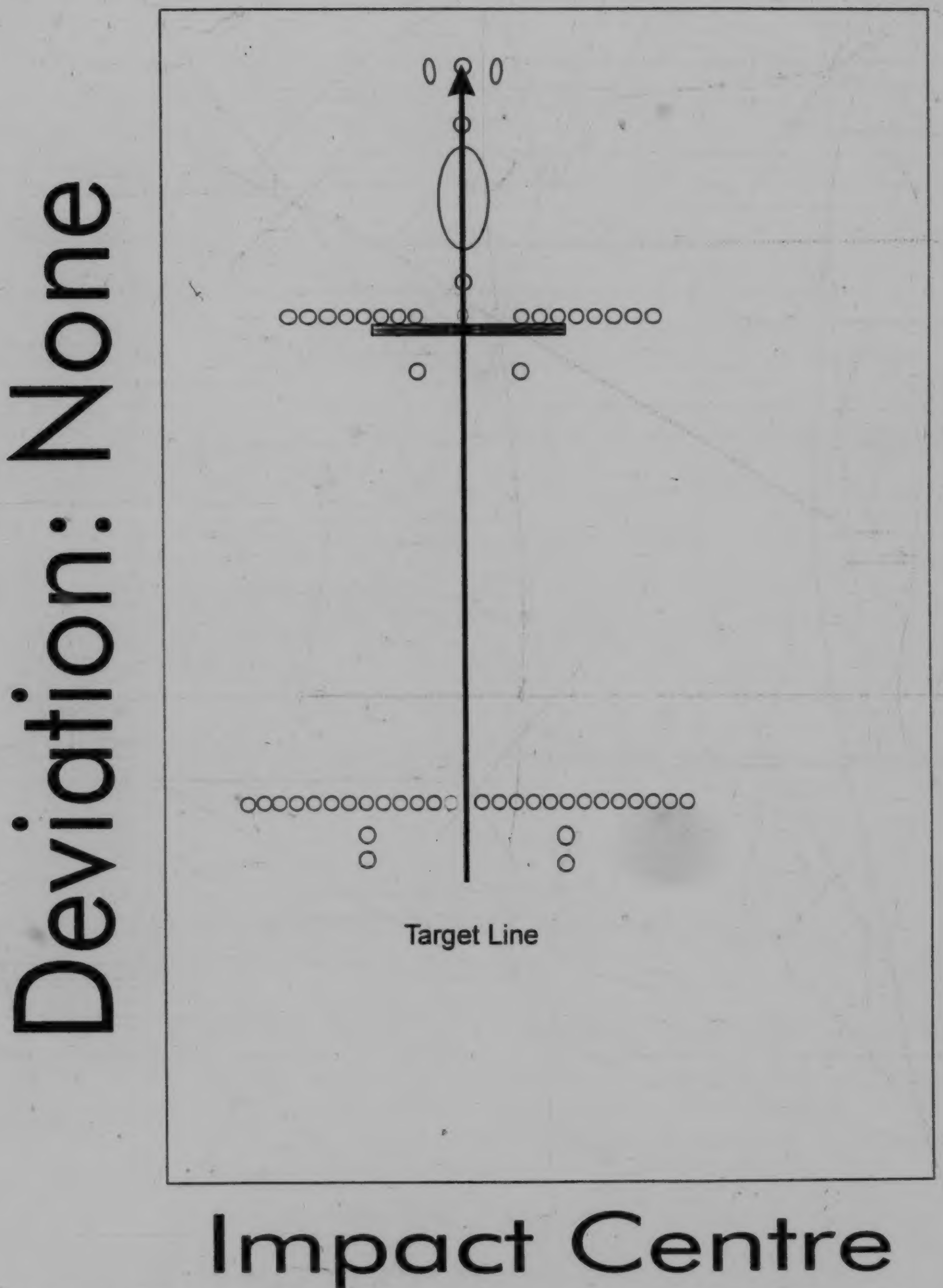

Deviation: None
Target Line
Impact Centre

Figure 5. Illustration depicting an impact on the centre of the clubface (0").

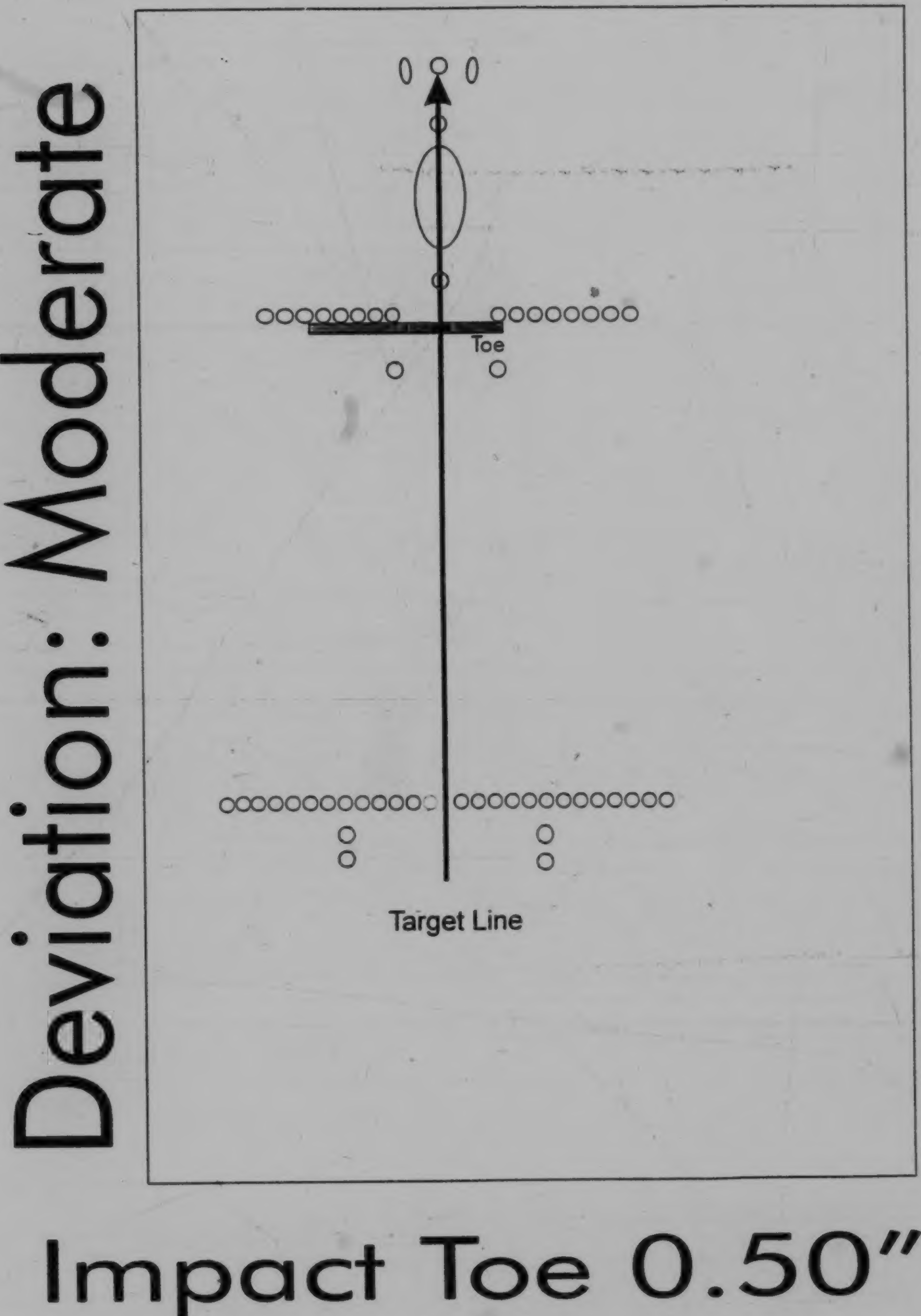
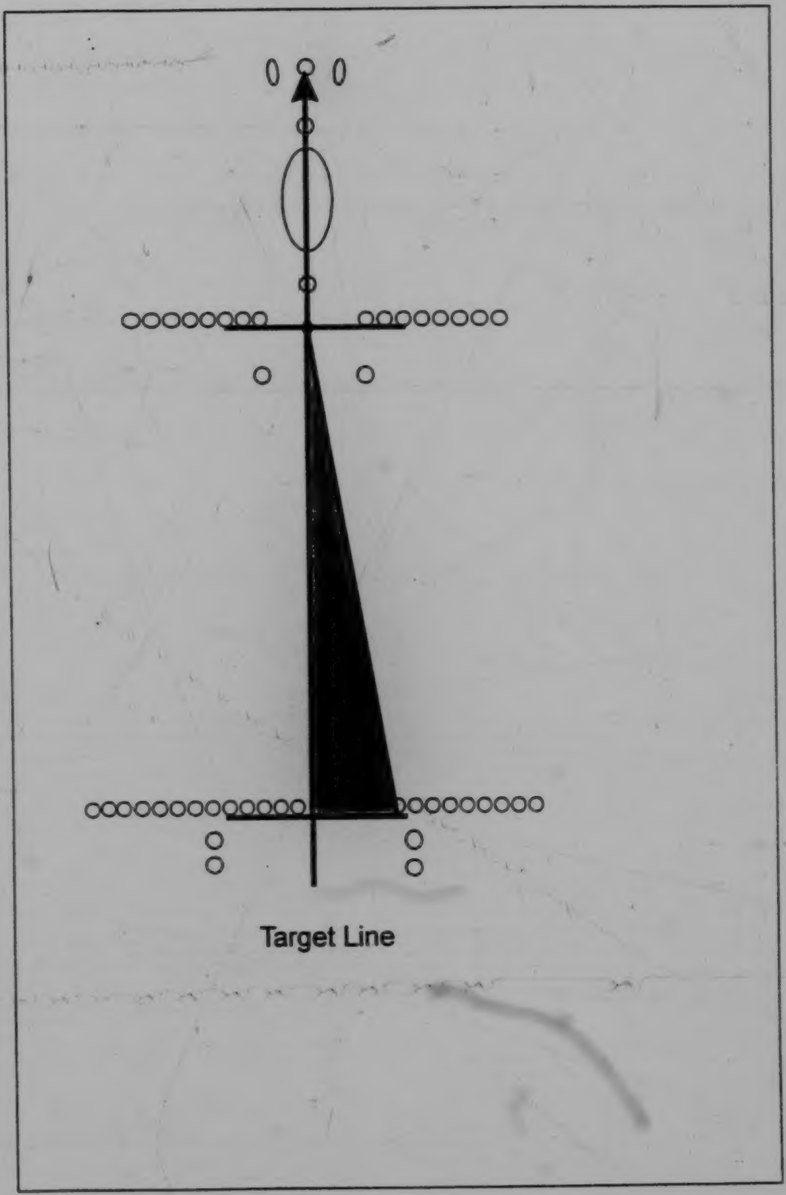

Deviation: Moderate
Toe
Target Line
Impact Toe 0.50″

Figure 6. Illustration depicting a moderate toe impact (0.50″).

Deviation: Large


Target Line

Swing path ≥8° Out-In

Figure 7. Illustration depicting a large out to in swing path (≥-8°).

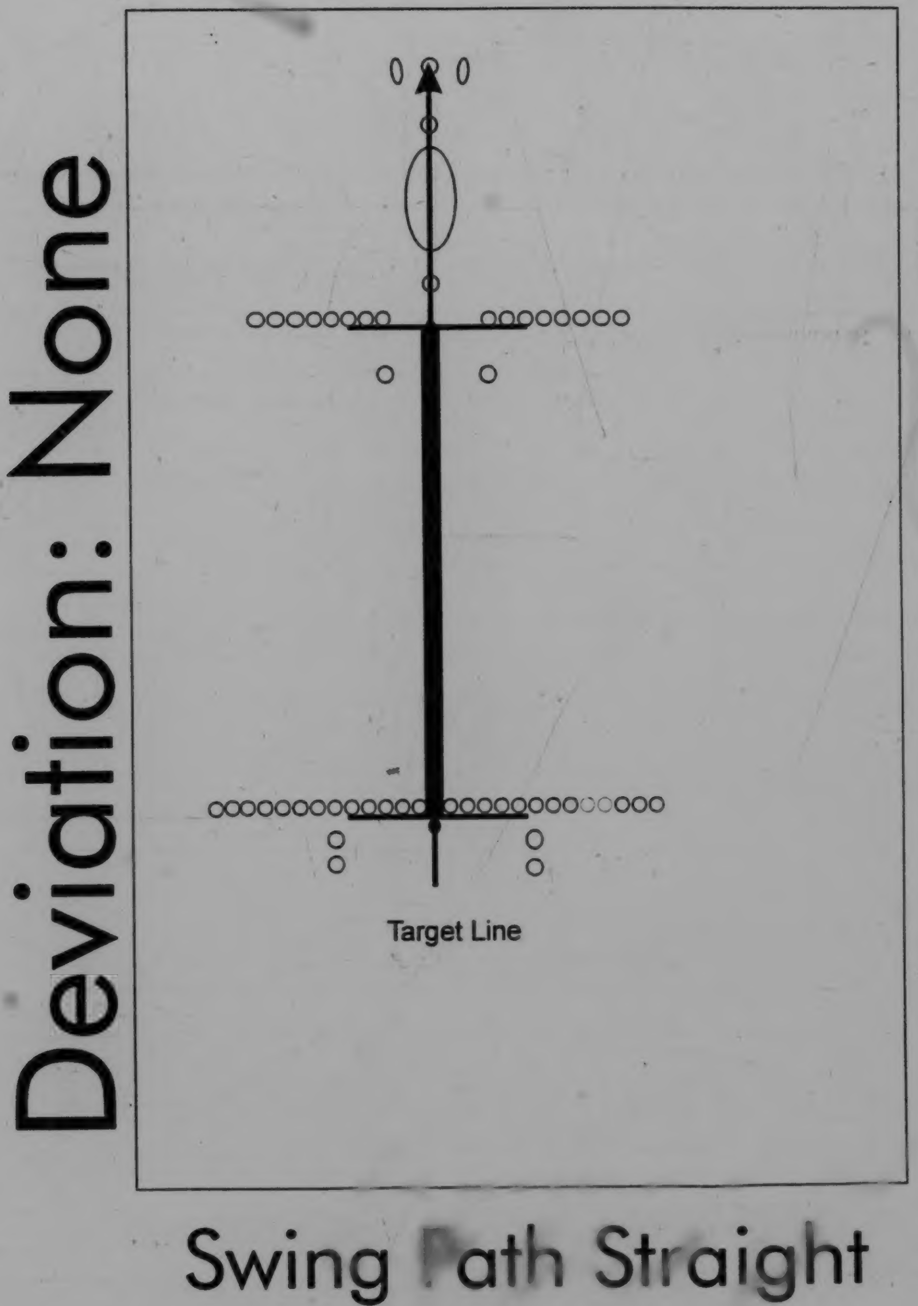

Deviation: None
Target Line
Swing Path Straight

Figure 8. Illustration depicting a straight swing path (0°).

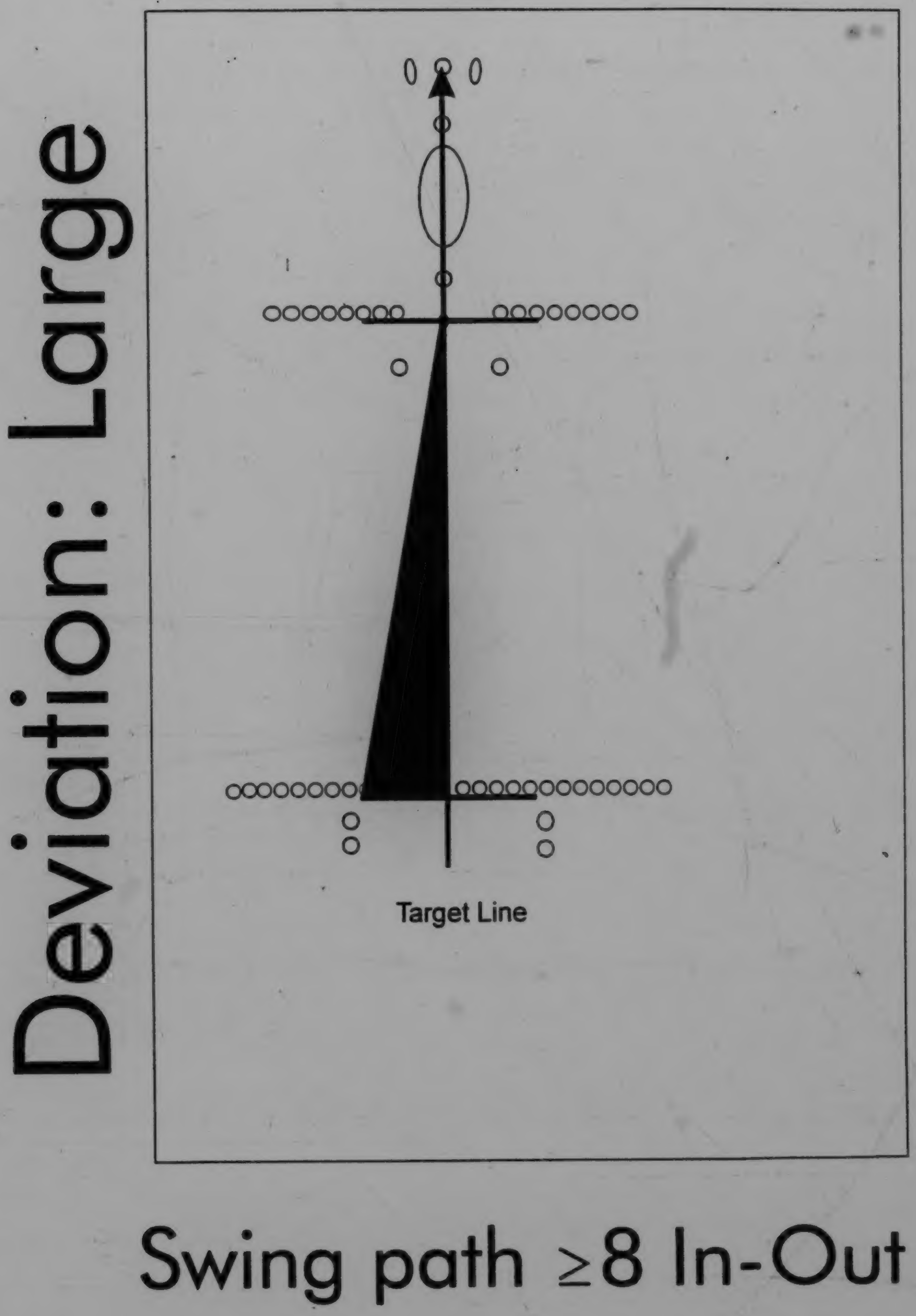

Deviation: Large
Target Line
Swing path ≥8 In-Out

Figure 9. Illustration depicting a large in to out swing path (≥8°).

APPENDIX C

SAMPLE OF PARTICIPANT PERFORMANCE DATA FOR STUDY TWO

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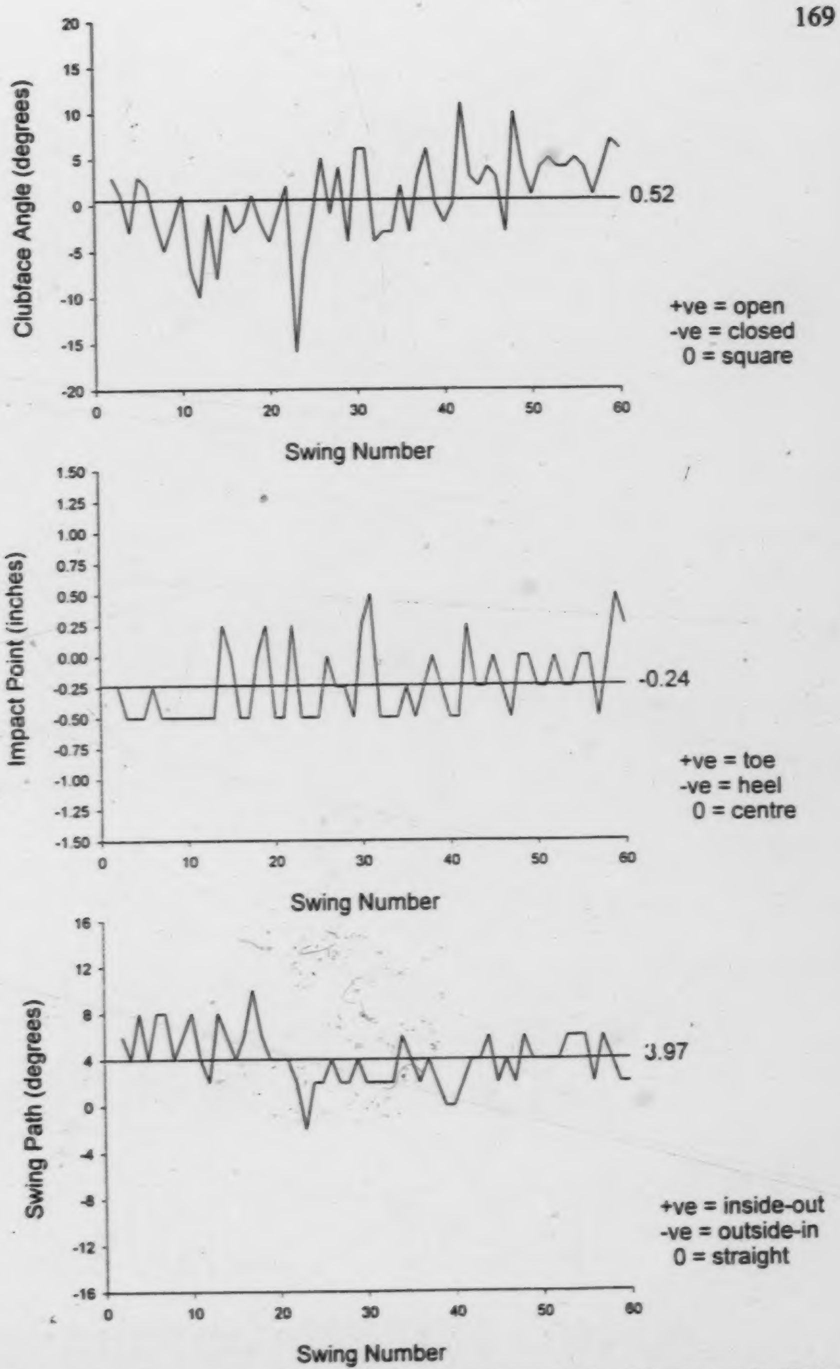

Figure 1. Actual performance scores of Participant #9 (Handicap = 2) for clubface angle (CA), impact point (IP), and swing path (SP). Horizontal line represents mean value for each parameter.

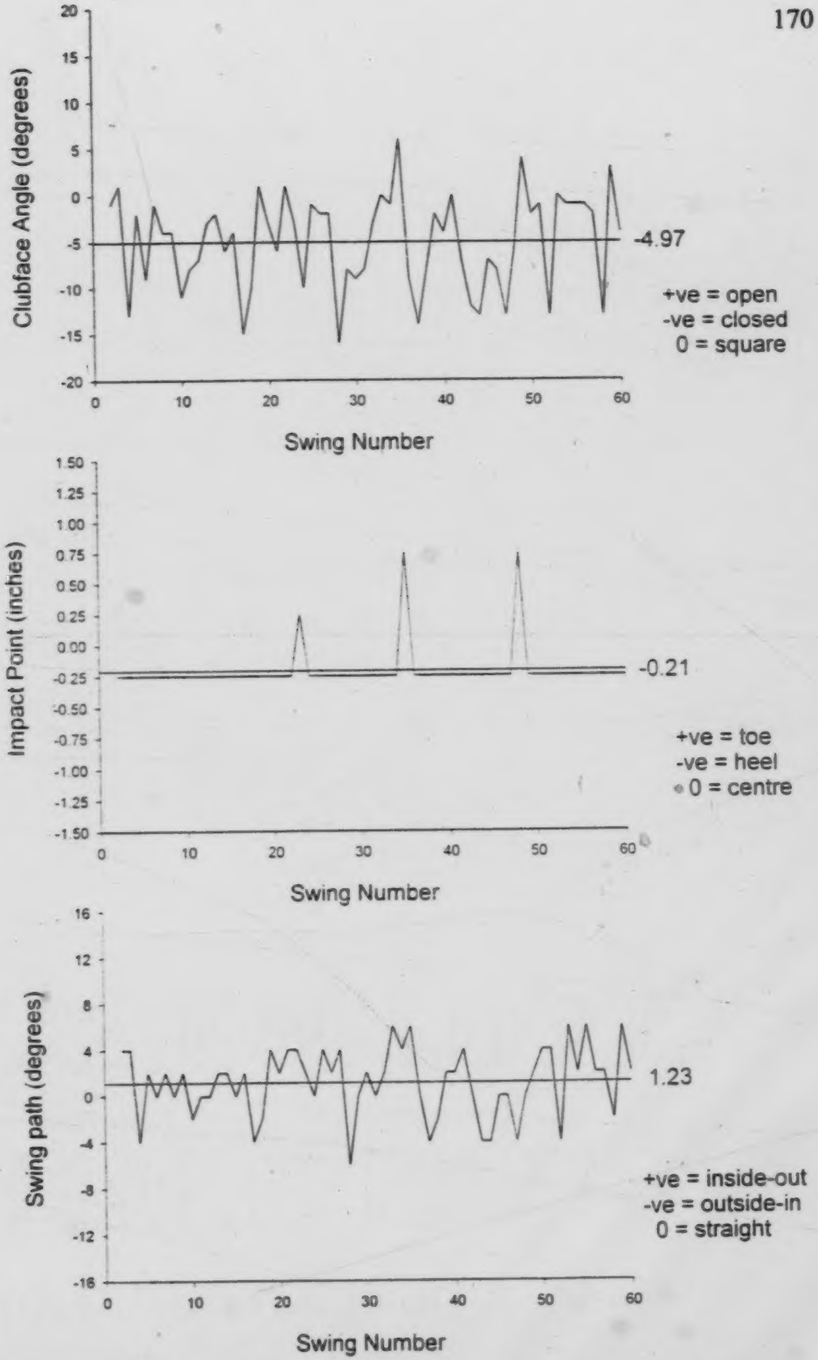

Figure 2. Actual performance scores of Participant #3 (Handicap = 6) for clubface angle (CA), impact point (IP), and swing path (SP). Horizontal line represents mean value for each parameter.

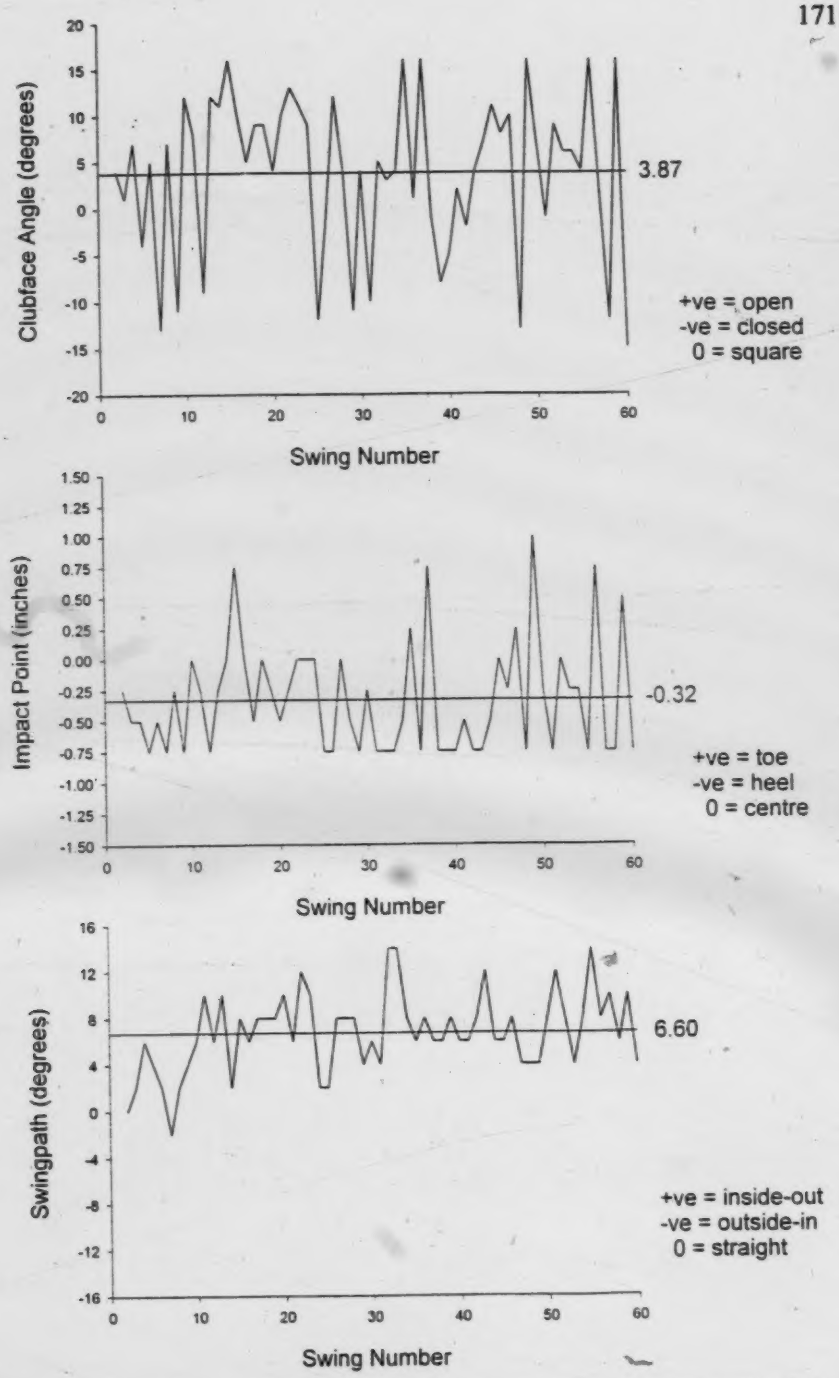

Figure 3. Actual performance scores of Participant #2 (Handicap = 10) for clubface angle (CA), impact point (IP), and swing path (SP). Horizontal line represents mean value for each parameter.

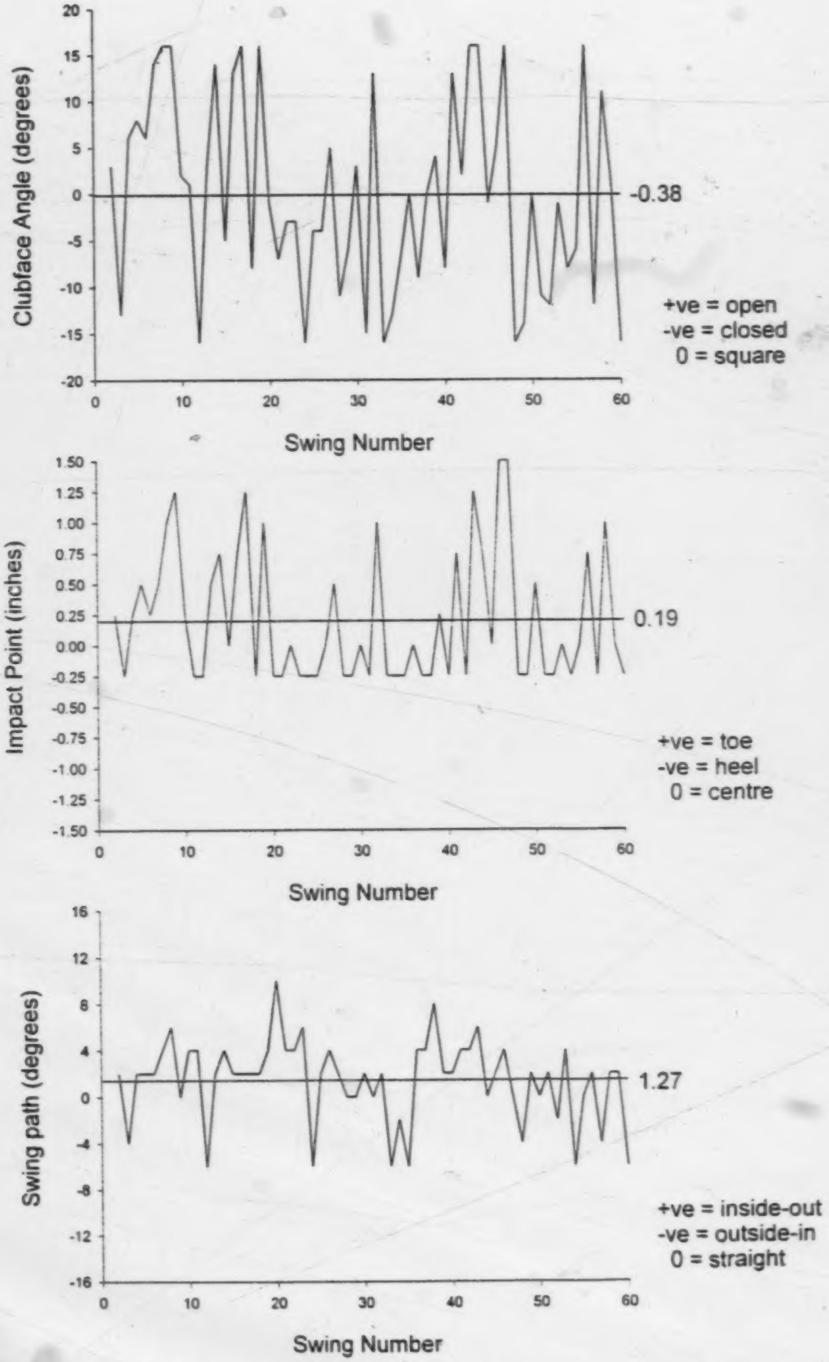

Figure 4. Actual performance scores of Participant #17 (Handicap = 20) for clubface angle (CA), impact point (IP), and swing path (SP). Horizontal line represents mean value for each parameter.

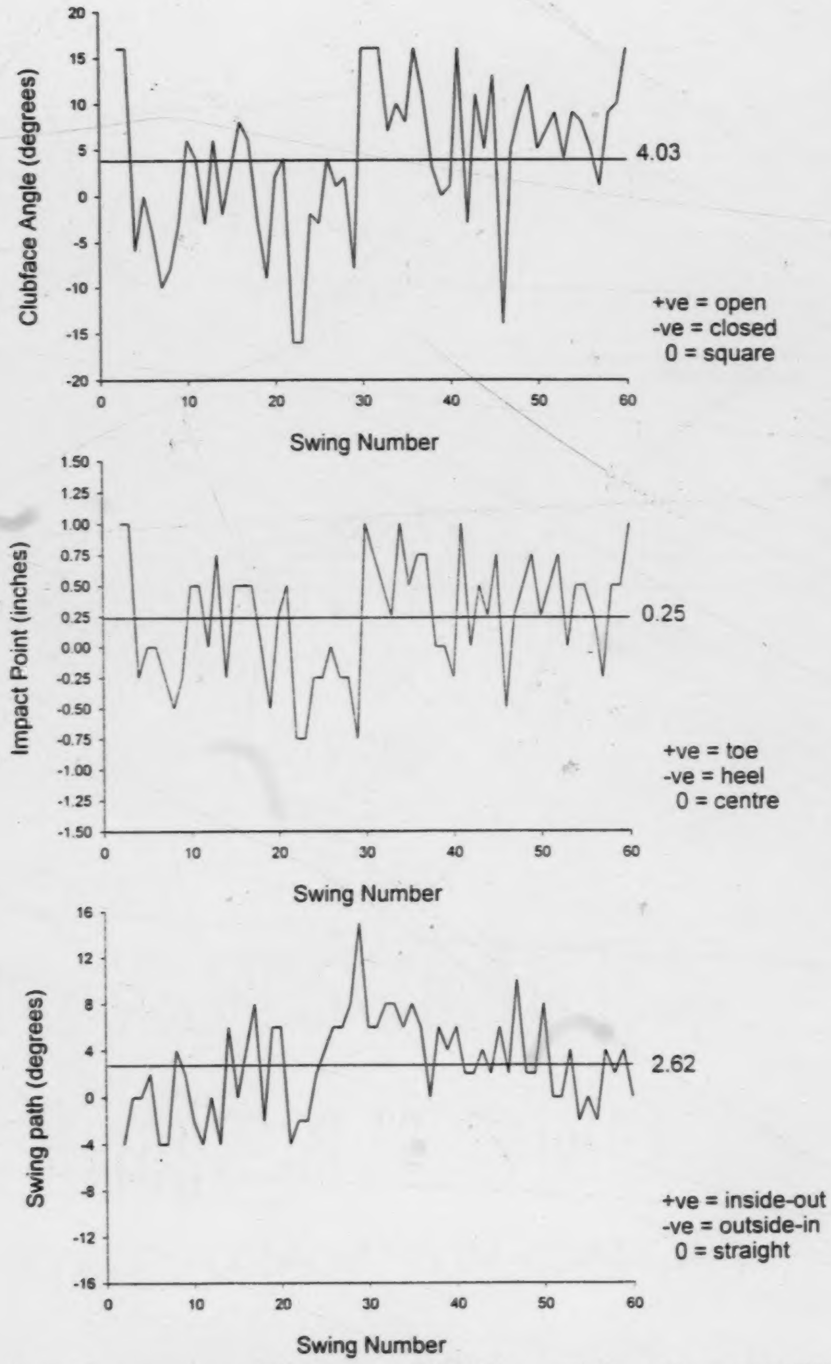

Figure 5. Actual performance scores of Participant #15 (Handicap = 26) for clubface angle (CA), impact point (IP), and swing path (SP). Horizontal line represents mean value for each parameter.

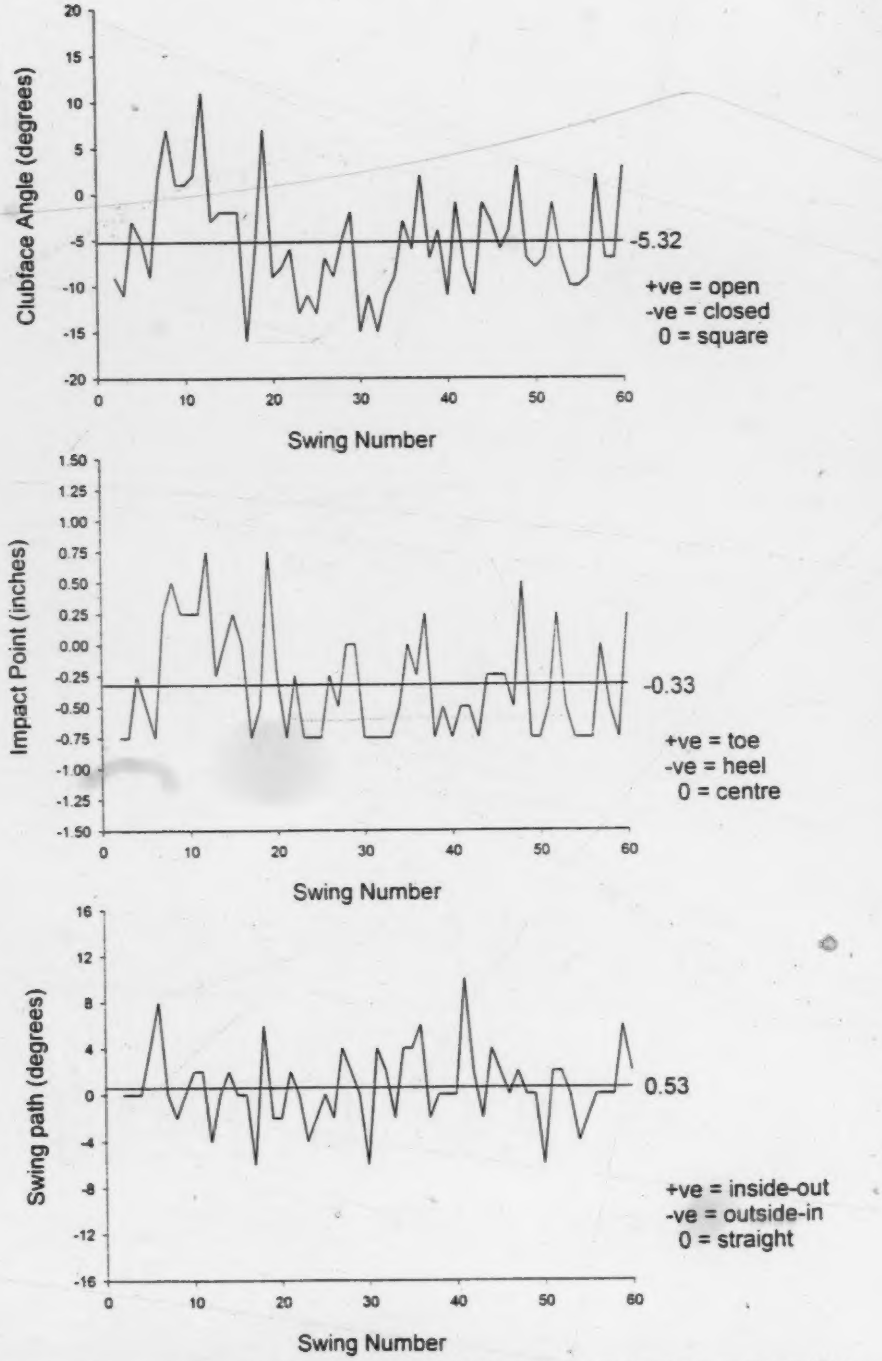

Figure 6. Actual performance scores of Participant #20 (Handicap = 30) for clubface angle (CA), impact point (IP), and swing path (SP). Horizontal line represents mean value for each parameter.

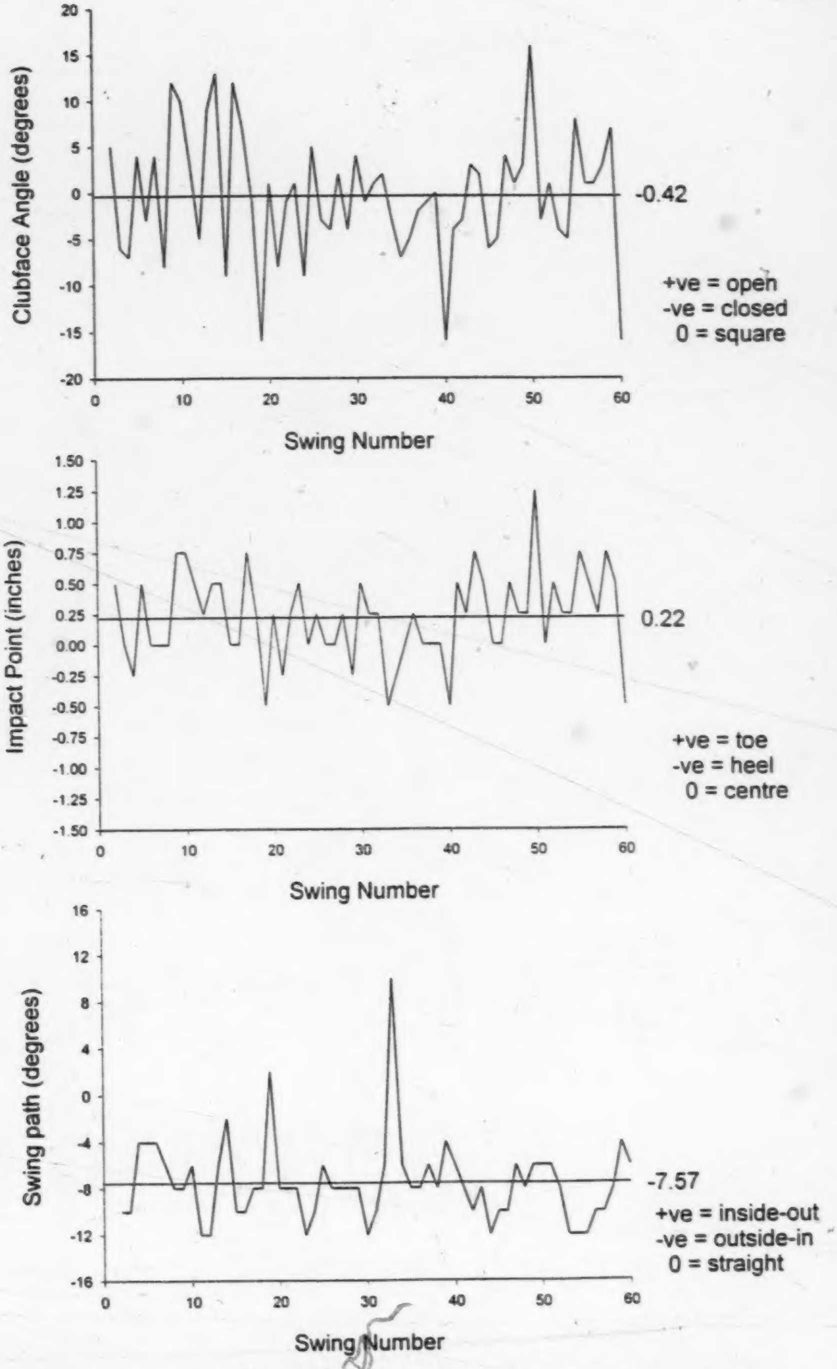

Figure 7. Actual performance scores of Participant #5 (Handicap = 8) for clubface angle (CA), impact point (IP), and swing path (SP). Horizontal line represents mean value for each parameter.

APPENDIX D

SAMPLE OF PARTICIPANT PERFORMANCE DATA FOR STUDY THREE

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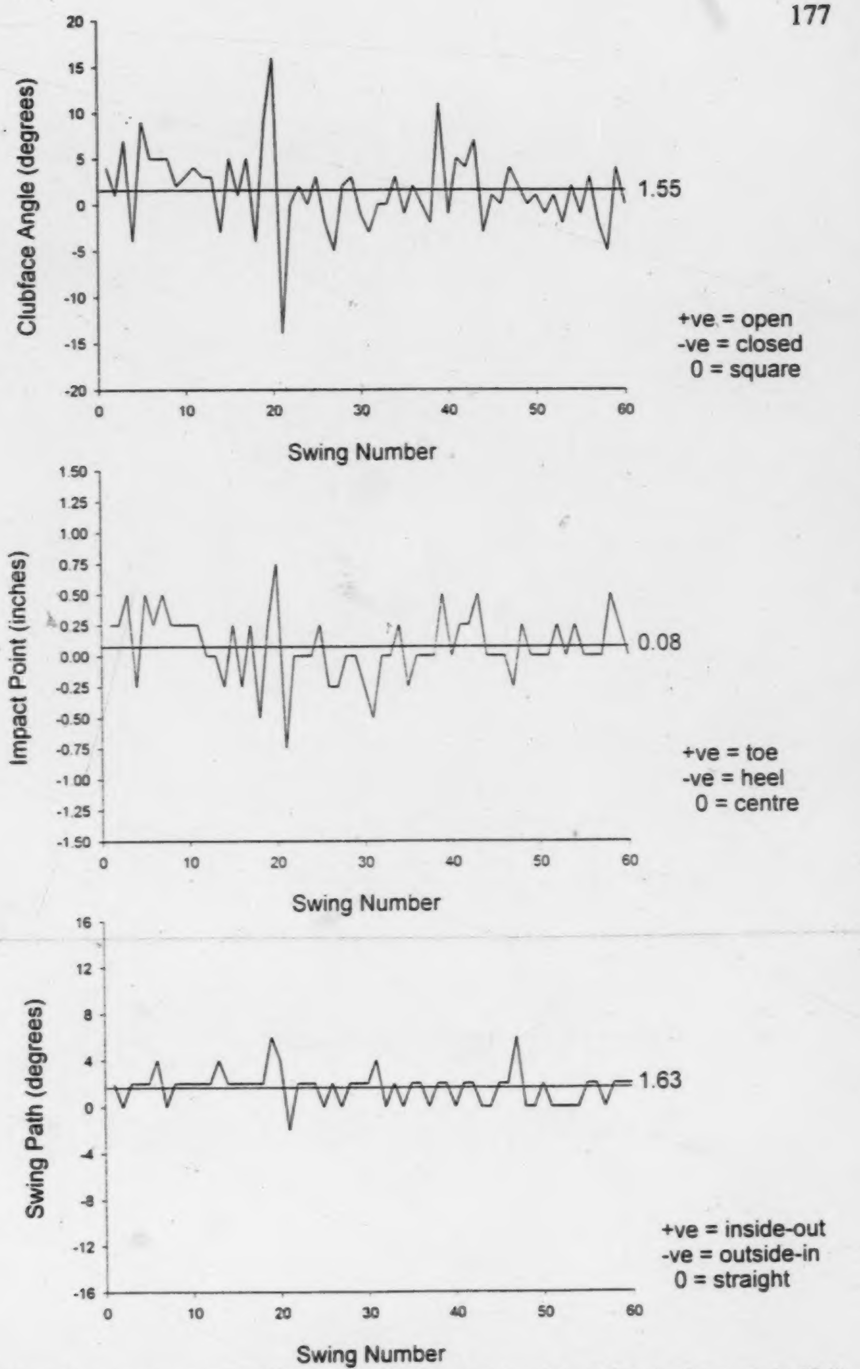


Figure 1. Actual performance scores of Participant #4 (scratch handicap) for clubface angle (CA), impact point (IP), and swing path (SP). Horizontal line represents mean value for each parameter.

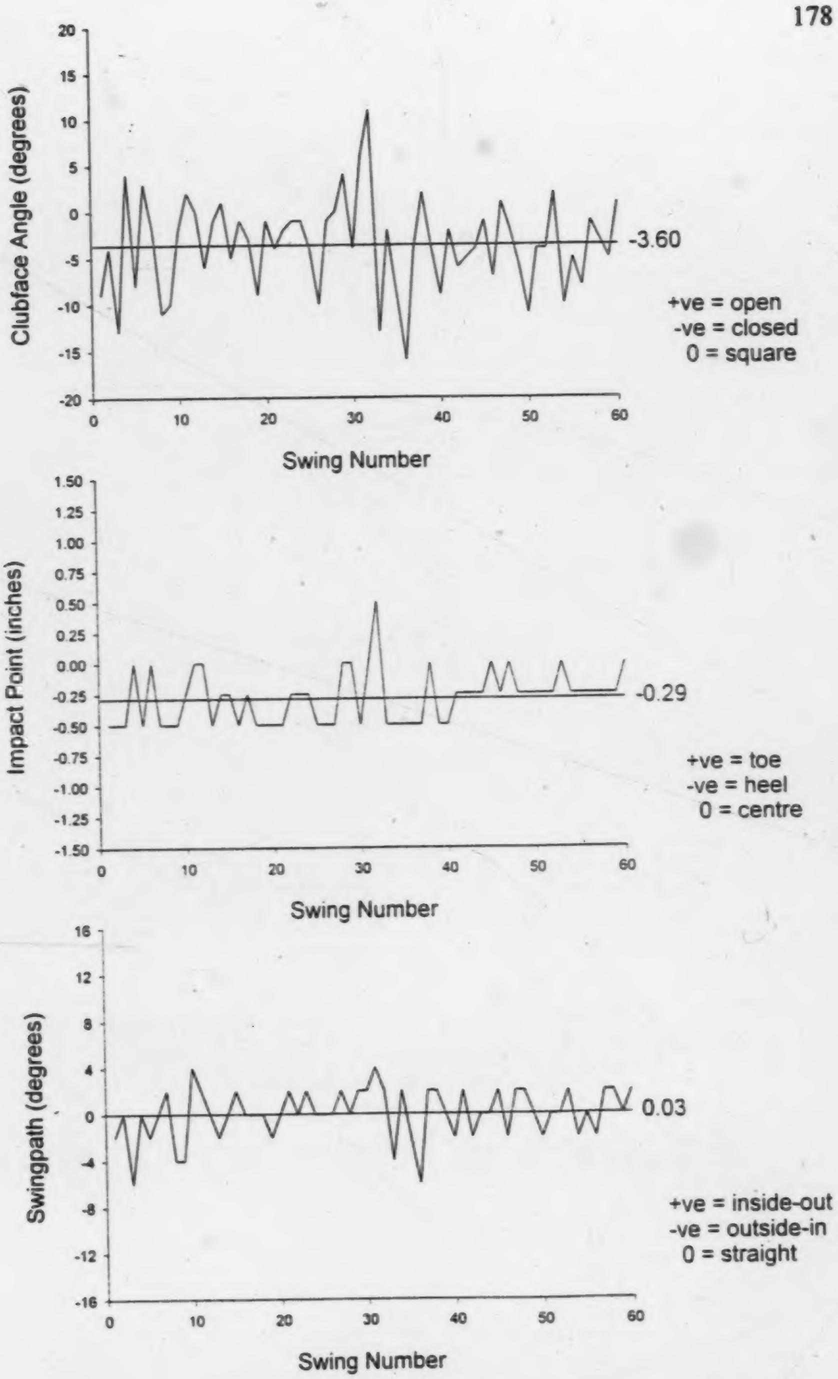


Figure 2. Actual performance scores of Participant #10 (Handicap = 6) for clubface angle (CA), impact point (IP), and swing path (SP). Horizontal line represents mean value for each parameter.

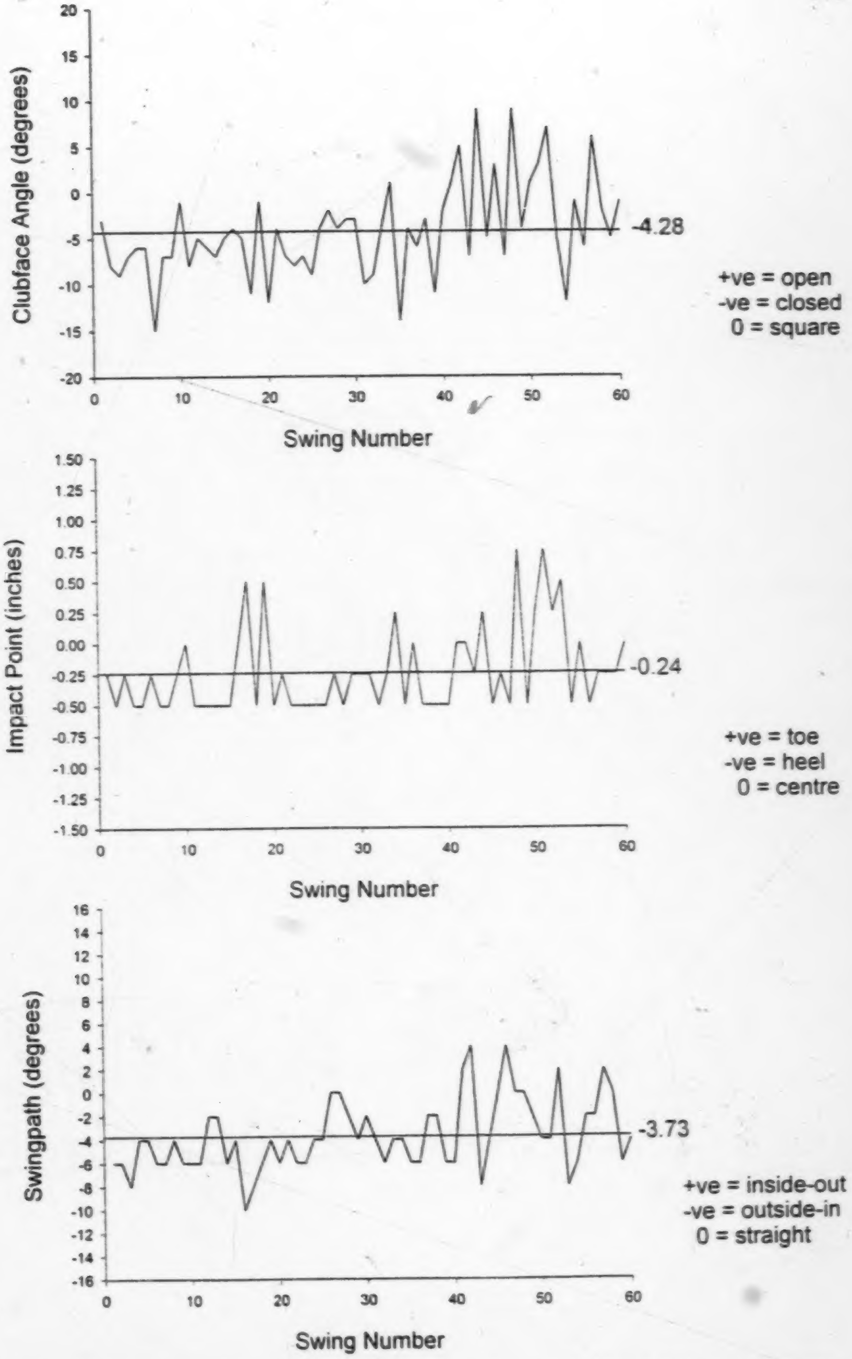
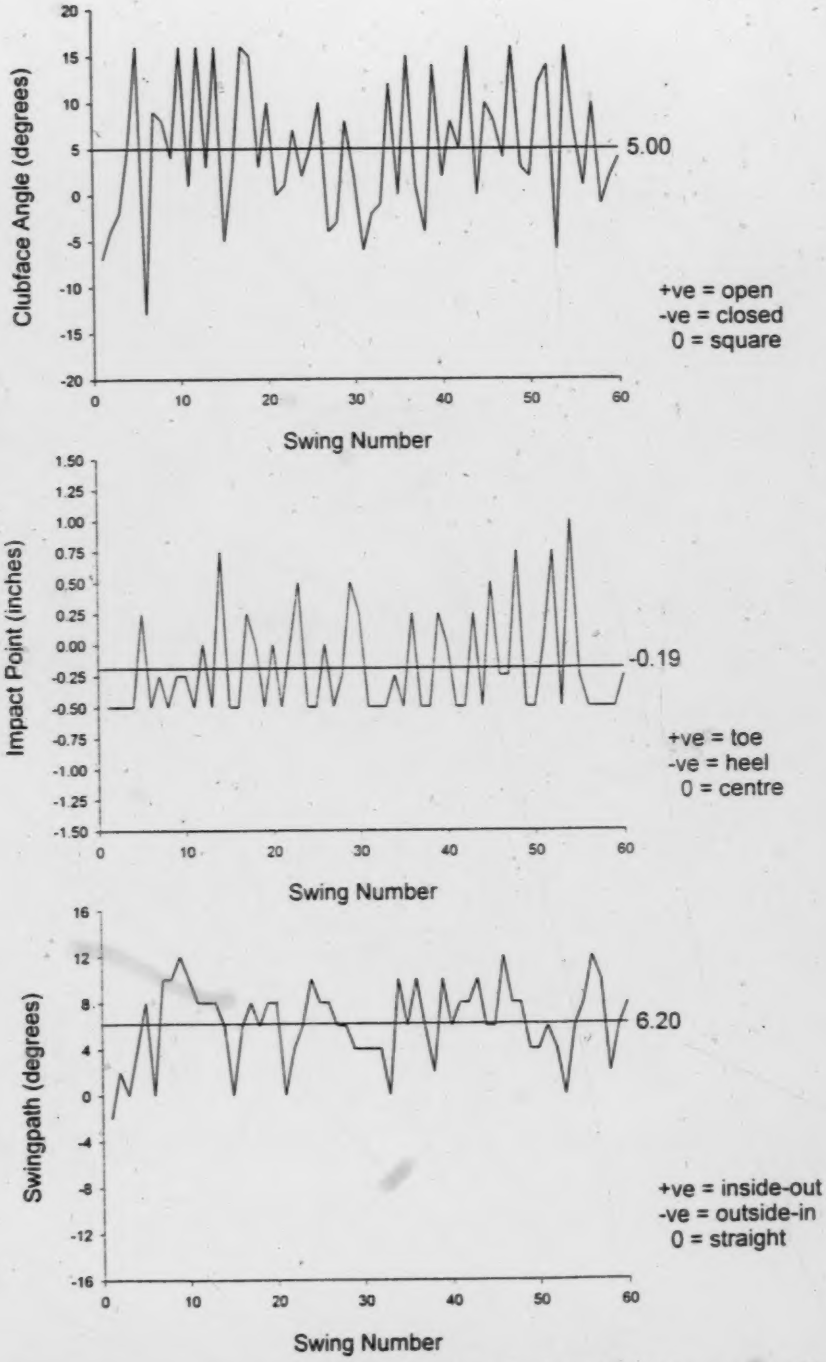


Figure 3. Actual performance scores of Participant #1 (Handicap = 10) for clubface angle (CA), impact point (IP), and swing path (SP). Horizontal line represents mean value for each parameter.



+ve = open
-ve = closed
0 = square

+ve = toe
-ve = heel
0 = centre

+ve = inside-out
-ve = outside-in
0 = straight

Figure 4. Actual performance scores of Participant #18 (Handicap = 20) for clubface angle (CA), impact point (IP), and swing path (SP). Horizontal line represents mean value for each parameter.

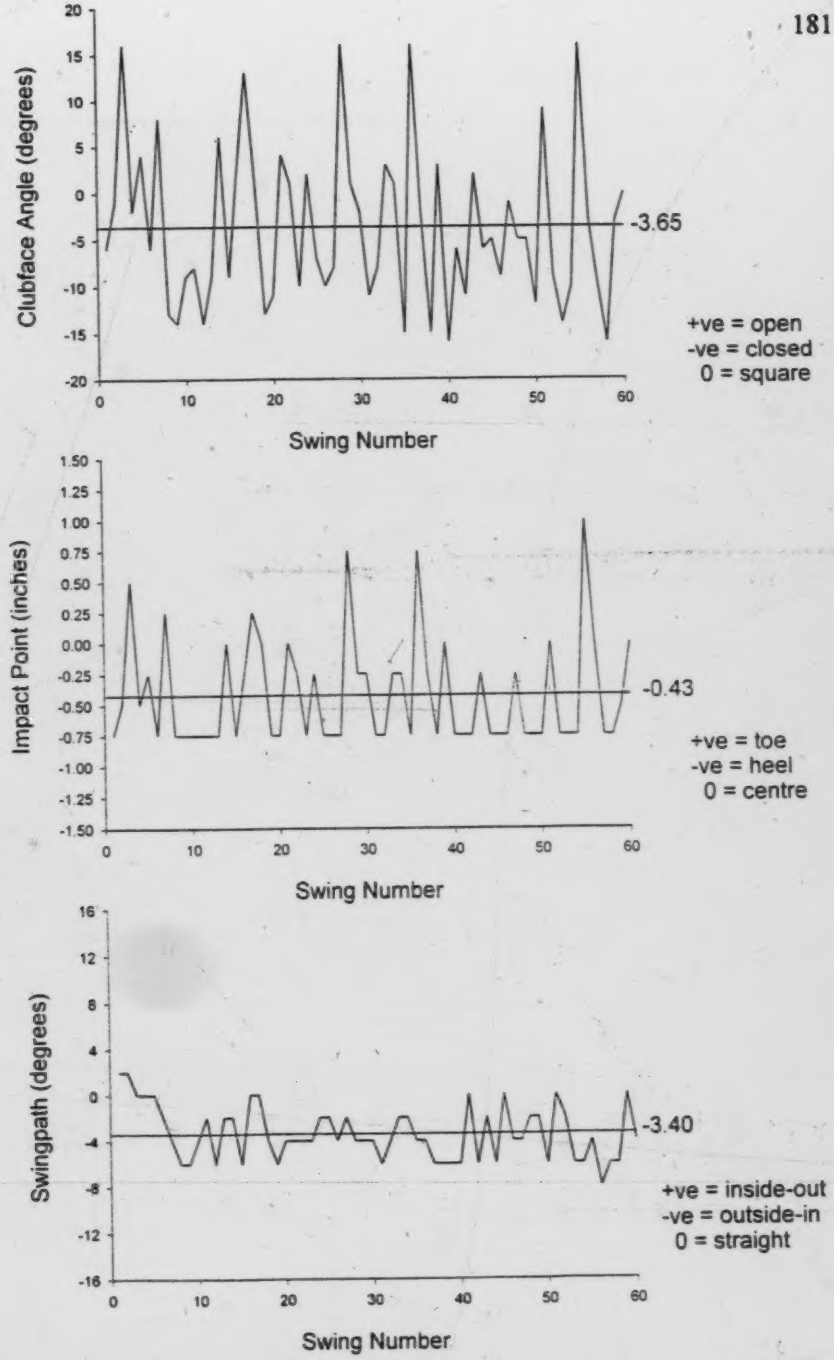


Figure 5. Actual performance scores of Participant #11 (Handicap = 26) for clubface angle (CA), impact point (IP), and swing path (SP). Horizontal line represents mean value for each parameter.

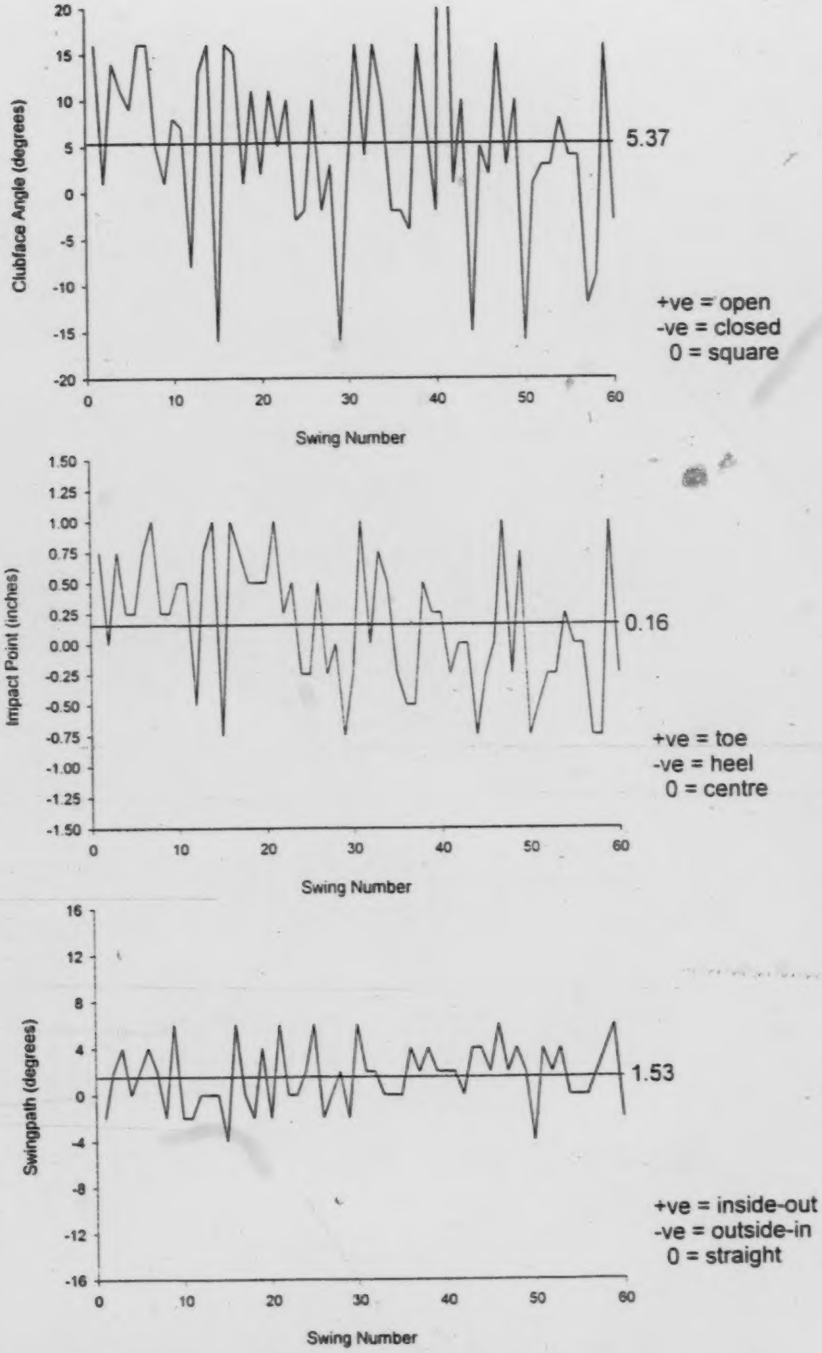


Figure 6. Actual performance scores of Participant #17 (Handicap = 30) for Clubface angle (CA), Impact point (IP), and Swing path (SP). Horizontal line represents mean value for each parameter.